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16. Abstract

ERTS MSS ratios derived from CCT's are very effective for quantitative detection of suspended solids up to at least 900 ppm. The relatively high inorganic suspended solids, characteristic of midcontinent reservoirs, dominates the reflected energy present in the four MSS bands. Dissolved solids concentrations up to 500 ppm and algal nutrients up to 20 ppm are not detectable. The MSS5/MSS4 ratio may be weakly correlated with total chlorophyll above ~ 8μg/l.

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Goddard Spaceflight Center
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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
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KANSAS ENVIRONMENTAL AND RESOURCE STUDY: A GREAT PLAINS MODEL

Monitoring Fresh Water Resources

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PREFACE

This is a final report on the progress achieved in the study of the major reservoirs in Kansas to determine the feasibility of monitoring fresh water resources by satellite. Two reservoirs, Tuttle Creek and Perry, have been the object of intensive study to determine the properties of reservoirs which control the spectral intensity of reflected sunlight as detected by the ERTS-1 sensors. Water samples have been collected from these two lakes concurrent with satellite overpass and have been analyzed to determine the amount of suspended solids, chlorophyll content, and concentrations of phosphate, nitrate, and potassium ions. In addition, water temperature and turbidity at each sample site were measured. ERTS images in four spectral bands (green, red, red-infrared, and infrared) were regularly received for each satellite overpass of Kansas reservoirs. CCT's have been obtained retrospectively for most of the usable passes over the two lakes. These have been processed and the output analyzed to determine the bands and combination of bands which best reflect water quality parameters measured at time of overflight. Film analysis has also been performed using the IDECS (Image Discrimination, Enhancement, and Combination System) together with the software system KANDIDATS (Kansas Digital Image Data System) which provides an analog-digital approach. Results of film analysis have been compared with those obtained using CCT's. Overall water quality of the 19 major reservoirs in the state has also been estimated qualitatively over the project period. Regional differences have been noted and interpreted.

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1.0 INTRODUCTION

In the North American Great Plains, where natural permanent lakes are a rarity, the dominant limnological feature today takes the form of man-made reservoirs. The major reservoirs in Kansas, as well as in other Great Plains states, are playing increasingly important roles in flood control, recreation , agricultural and urban water supply and wildlife management. The primary influence on the reservoir ecosystem is the suspended load and chemicals carried in by streams and rivers. The reservoirs are typically shallow and thus are susceptible to mixing by strong winds which are a characteristic climatic feature of this region. Wind generated currents are of sufficiently high velocity to maintain a sizable fraction of the silts and clays in suspension and the result is turbid water (mean light extinction coefficient = 2.45 meter $^{-1}$). A method for acquiring timely low cost water quality data is needed to achieve optimum management of these fresh water resources.

A number of state and federal agencies in Kansas have expressed the need for repetitive water quality data such as suspended solids, dissolved solids, chlorophyll, and the algal nutrients. Some specific problems this data would apply to are discussed in the next several paragraphs.

The Forestry, Fish and Game Commission (FFGC) estimates that at least $18 million is spent annually by sport fisherman in Kansas. To help insure continued growth and good health for the sport fishing industry, the FFGC is undertaking a new study on all major reservoirs in Kansas to determine the effect of water environment on fish spawning and subsequent fish population. It is felt that the level of suspended solids significantly affects spawning and subsequent fish population. A knowledge of suspended load distribution in the lake would allow better fish management. Suspended load maps over a period of time would help to identify the best spawning areas within a reservoir and also would identify source points of undesirable high suspended load.

The Kansas State Health Department (KSHD) is concerned about the unpredictable occurrences of feedlot waste coming in contact with some of the city lakes used for drinking water. Feedlot waste usually contributes to the suspended load which is dectable by ERTS. The KSHD is also concerned with chlorophyll and dissolved solids in the city lakes. The federal guideline of 500 PPM maximum allowable dissolved solids is often exceeded in the state of Kansas.

Temporal data on sediment load and source point location would allow better estimates of reservoir lifetime. Unusually high increases in sediment load/algal nutrients might permit timely identification of poor cultivation/fertilization practices upstream.

The goal of this ERTS-1 study is to test the feasibility of using satellite imagery to monitor suspended load and chemical concentrations in Kansas reservoirs, which should be representative of most Great Plains reservoirs. Figure 1 shows the distribution of the nineteen federal reservoirs in Kansas and the ERTS-1 ground traces over the state. These reservoirs were built by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation within the last 35 years. At normal pool elevation these water bodies have large surface areas relative to ERTS resolution. The surface areas vary from about 3 square miles at Lovewell to about 25 square miles at Tuttle Creek. The shortest dimension of the main part of any of the reservoirs is approximately 1/2 mile. The largest dimension is about 20 miles Depths vary from 40 to 50 feet at the dam to 1 to 2 feet at the upper end. Normal pool capacities vary from 10,000 to 500,000 acre - feet of water. In addition to the 19 major reservoirs there are approximately 100 smaller lakes in the state of Kansas with surface area greater than 20 acres as well as numerous stock ponds and ephemeral lakes which are detectable on ERTS-1 imagery.

The nineteen major reservoirs of Kansas are well distributed throughout the state occurring in a number of physiographic and land use regions that adequately represent much of the Great Plains environment. Lakes in extreme eastern Kansas lie within the humid portion of the state that is dominated by corn belt type agriculture. Lakes in central Kansas located within the Flint Hills and Smoky Hills escarpments collect drainage from important livestock grazing regions. These reservoirs farther west in the semi-arid High Plains are in an important wheat and cattle producing area. Most of these lakes are operated by the Bureau of Reclamation and some are used for irrigation. Lakes in eastern Kansas are operated by the Corps of Engineers.

Two reservoirs, Perry and Tuttle Creek, were singled out for close study. Approximately ten water samples from each reservoir were collected during each cloud-free ERTS overpass for a 13 month period and analyzed for concentrations of inorganic suspended and dissolved solids, organic suspended and dissolved solids, chlorophyll, potassium, phosphate, and nitrate ions. In addition, secchi disc and temperature measurements were taken at each sampling station. Wind velocity and lake level were also recorded. These two reservoirs are distinct in terms of the geology and land-use of their watersheds. Perry lies in the Corn Belt of Eastern Kansas in an area that was glaciated during the Kansas stage of Pleistocene glaciation. Tuttle Creek lies farther west in the northern portion of the Flint Hills and has a watershed underlain by Permian and Cretaceous rocks where livestock grazing and small grains production are important. Occasionally samples were collected from Milford Reservoir which lies 20 miles southwest of Tuttle Creek.

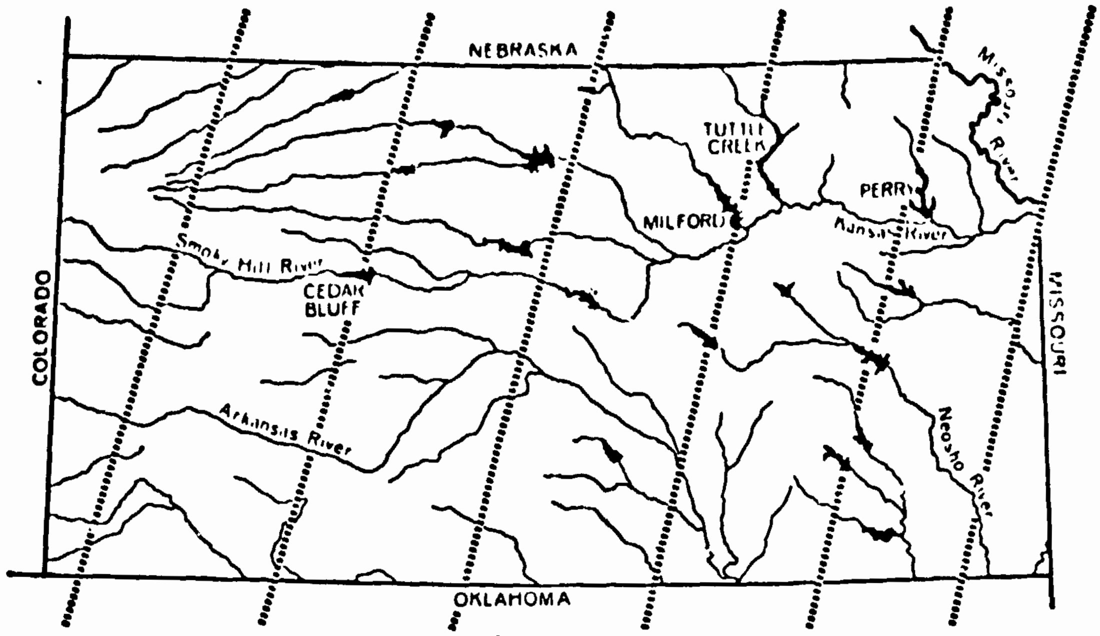


FIGURE 1. RESERVOIRS AND ERTS TRACKS IN KANSAS

CATEGORY	CYCLES	%
TOTAL ERTS CYCLES OVER PERRY AND TUTTLE CREEK RESERVOIRS	46	100
CLOUD FREE CYCLES	25	54
CLOUD FREE CYCLES WITH GROUND TRUTH	18	39
CLOUD FREE CYCLES WITH GROUND TRUTH AND IMAGERY	15	33
CLOUD FREE CYCLES WITH GROUND TRUTH AND CCT'S	16	35

FIGURE 2. SUMMARY OF DATA ACQUISITION FROM PERRY AND TUTTLE CREEK RESERVOIRS DURING JULY 25, 1972 TO AUG. 27, 1973.

2.0 DATA ACQUISITION AND REDUCTION

Ground truth and imagery were accumulated during the first 23 ERTS-1 cycles over the state of Kansas. Of the 46 combined cycles over Perry and Tuttle Creek Reservoirs, 25 were cloud free (figure 2). Water samples (grab samples from first 30 cm. of water) were collected for 18 of the 25 cloud free reservoir cycles. Conditions such as ice cover, high wind and mechanical failure prevented sample collection for the remaining 7 cloud free cycles.

Four bands of MSS imagery in the form of 9-inch black-and-white positive transparencies were acquired for 15 of the 18 cloud free cycles with ground truth. MSS computer compatible tapes (CCT's) were acquired for 16 of the 18 cloud free cycles with ground truth. Figure 3 relates successful cloud free cycles to time of year and sun angle.

The suspended and dissolved solids were determined using normal evaporation plus gravimetric procedures. Dissolved solids are defined as material surviving a 0.45 micron filter. The inorganic fraction of suspended and dissolved solids is defined as material that survived 1 hour at 600°C. Chlorophyll a, b and c concentrations were determined by acetonic extraction (Richards and Thompson 1952) and subsequent spectrophotometric measurement (Vollenweider 1969). Nitrate, phosphate and potassium concentrations were determined spectrophotometrically (APHA 1965) on a Beckman DU Spectrophotometer.

Digital levels for each water sample were extracted from the CCT by locating the sample station coordinates on a CCT generated computer printout gray level map, then averaging 9 pixels centered around the coordinate which corresponds to a 240 x 240 meter square area on the water surface.

The water quality data along with secchi depth, temperature, lake level, wind speed and CCT digital levels were entered onto a disc file accessible by a time-sharing terminal. This data is stored in permanent form on punched paper tape. This data was used to search for quantitative correlation between MSS imagery and water quality parameters. The results of this search are presented in section 3 through 9. The 9" positive transparencies for each MSS band were electronically sliced and displayed on our IDECS system. The color coded displays were recorded on 35 mm film for permanent storage and further analysis. The level slicing was done on the basis of equal vidicon output voltage intervals which is equivalent to equal log density intervals. The maximum number of levels/image was determined by the dynamic range of the particular band over the reservoir surface and varied from 2 to 8 levels. The equal gray levels selected by IDECS correspond to nearly equal reflected energy

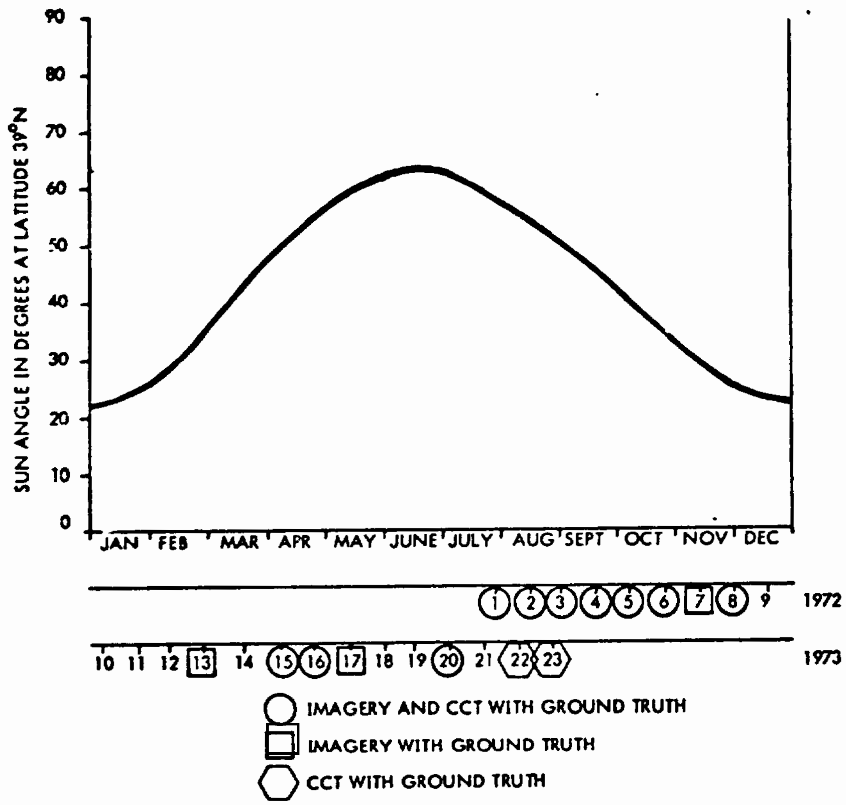


FIGURE 3. DATA ACQUISITION AS A FUNCTION OF TIME OF YEAR, SUN ANGLE, AND ERTS CYCLE NUMBER.

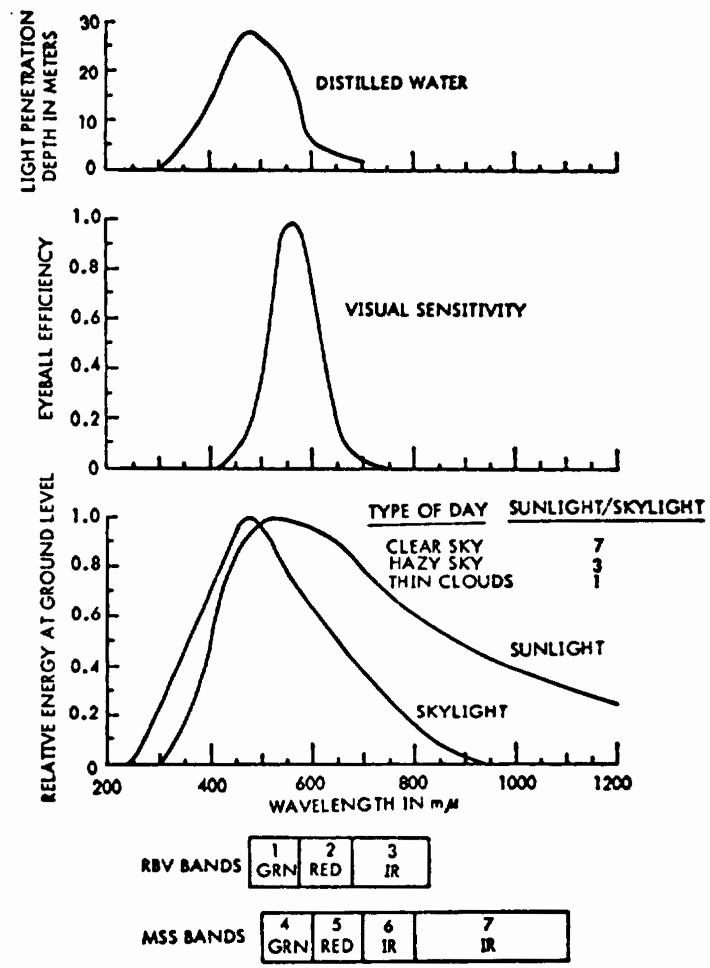


FIGURE 4. RADIANCE vs WAVELENGTH.

intervals as defined on the NASA 15 step gray tablet. Maximum density variation (~ 0.6 to 1.7) is usually found on the red band (MSS5) and corresponds to a power return range of 0 to ~ 25%.

The IDECS data was used as a qualitative guide in the study of quantitative correlation between water quality parameters and MSS CCT's. The correlation between MSS transparencies and CCT's is discussed in section 10.

As work progressed on this project, a number of papers were presented at various symposia. Most of these are available in proceedings and are listed in the references (Marzolf et al. 1973, McCauley and Yarger 1973, McCauley et al. 1973, Yarger et al. 1972, Yarger et al. 1973 a and b.)

3.0 SUN ANGLE EFFECTS

The multispectral scanner (MSS) in ERTS records light reflected from a scene illuminated by an admixture of sunlight and skylight (Figure 4). On relatively clear days the spectral shape of the illumination remains fairly constant throughout the year. However, the intensity, angle of incidence, and path length through the atmosphere depend on sun angle (angle above horizon). The reflectance levels from the concrete dam at Tuttle Creek Reservoir, a target with constant spectral reflectance, demonstrate a strong sun angle dependence in all MSS bands (Figure 5). As has been suggested by Vincent (1972), the sun angle dependence is suppressed by plotting band ratios instead of absolute levels (Figure 6). The three other possible ratios, not plotted in figure 6, also show a flat response to change in sun angle. Ratioing essentially removes the effect of unequal illuminating intensities caused by the continuously changing sun angle from one ERTS pass to the next. Since the ratio curves for the dam are flat, the angle of incidence and atmospheric scattering of reflected light are not important factors, at least for a concrete target.

Water reflectance levels do not exhibit as strong a dependence on sun angle, but there is a significant measureable effect (see Figure 7 for band 5 example). As for concrete, the absolute, reflectance levels for water decrease with lower sun angle. After ratioing (figure 8) the three passes appear to be statistically similar. Dark object subtraction on each band before ratioing, as suggested by Vincent (1972), does not significantly change the ratio curves in Figure 8. Dark object subtraction, which is the absolute level detected by ERTS minus level of darkest object in scene, should suppress atmospheric scattering effects present in the ratios.

These results suggest that the point scatter present in figure 8 are not due to atmospheric scattering. For the remaining discussion it is assumed that, after ratioing, sun angle dependence and atmospheric scattering are relatively unimportant.

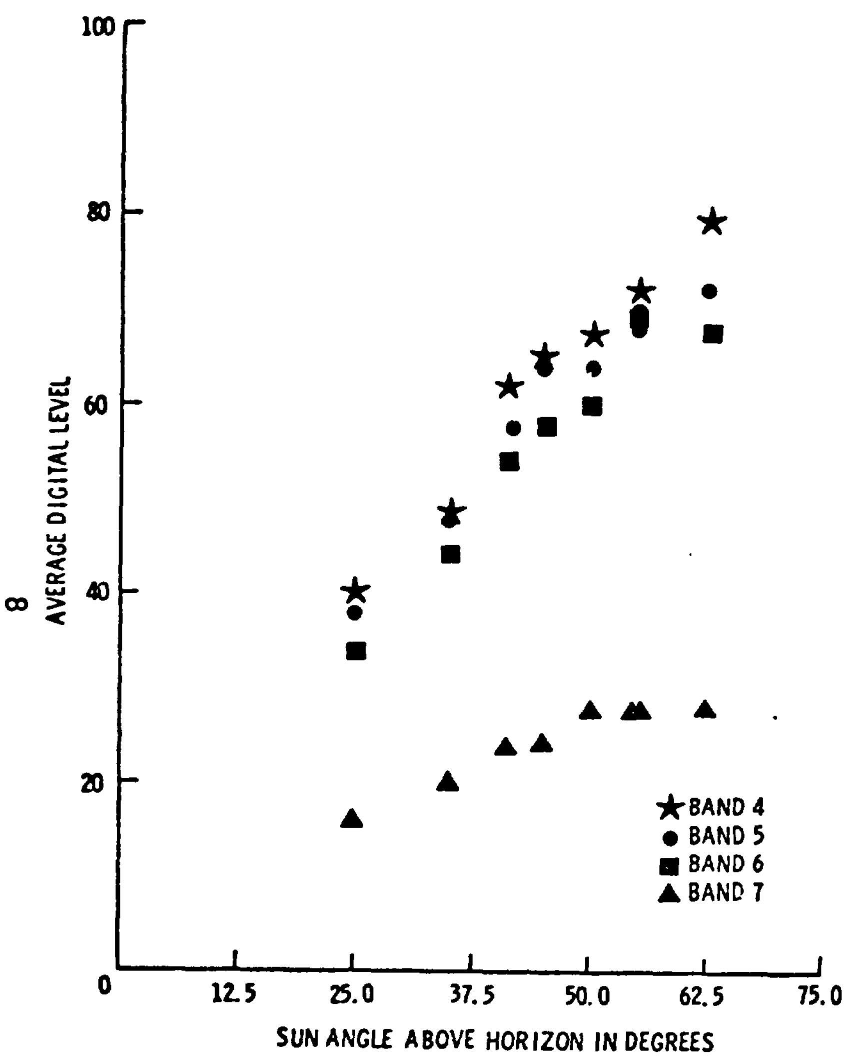


FIGURE 5. MSS DIGITAL LEVELS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

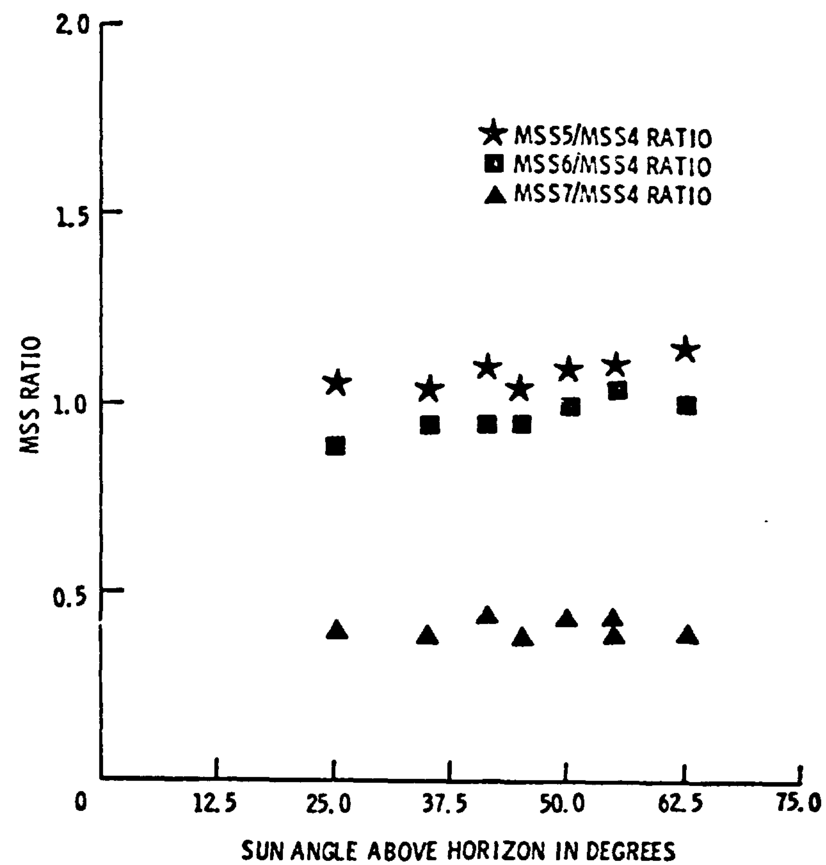


FIGURE 6. MSS BAND RATIOS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

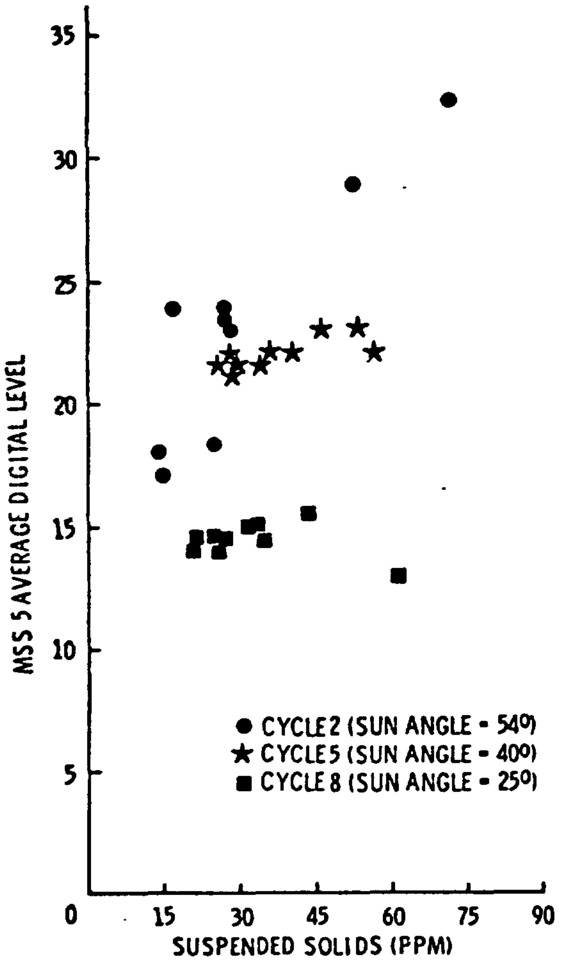


FIGURE 7. MSS5 DIGITAL LEVELS FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 ERTS-1 CYCLES.

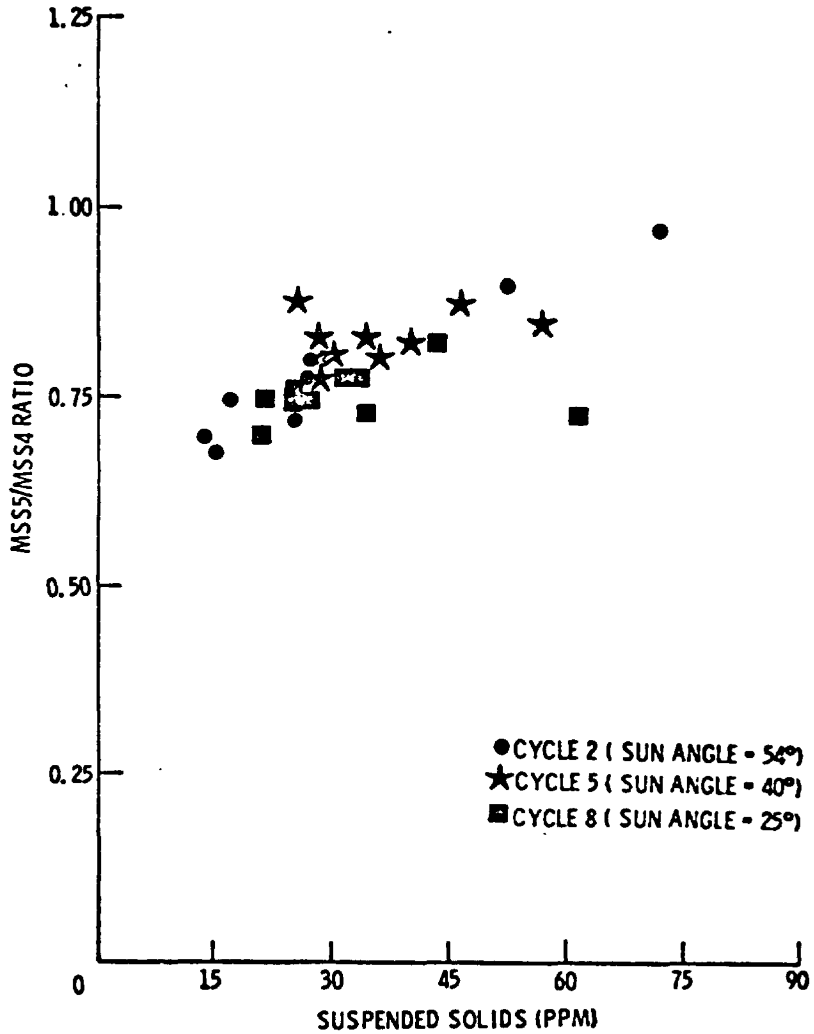


FIGURE 8. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 ERTS-1 CYCLES.

4.0 SUSPENDED SOLIDS

In general, bands 4, 5 and 6 (green, red, and near IR) exhibit substantial gray level variation across a reservoir surface. This gray level variation which is related to reflected energy detected by ERTS is highly correlated to the suspended sediment pattern in the reservoir. Bottom reflection is not a factor, because the reservoir bottom was not visible at any sample station. The subsequent figures relate CCT digital levels (which are linearly proportional to reflected energy) to suspended load.

Band 4 shows no correlation beyond ~ 50 ppm and is useful only for relatively clear water (Figure 9). This green band penetrates the water column more than the other bands (Figure 4), but as a consequence encounters a large amoung of scattering material which produces saturation or maximum scattering at suspended solids levels $\gtrsim$ 50 ppm. Band 5 (figure 10) is correlated with somewhat higher suspended solids ($\lesssim$80 ppm) but its response to suspended load is quite similar to band 4. Band 6 exhibits good correlation over the entire range 0 to 240 ppm (figure 11). The band 7 reflection levels are very low, but still show some correlation with increasing suspended load (figure 12).

As expected from the analysis in section 3.0, Band 5 ratioed with band 4 (figure 13) improves suspended load correlation and is roughly linear in the range of 0 to 80 ppm with RMS residual of 12 ppm. All regression fits displayed in subsequent figures were done with horizontal axis as the dependent variable and vertical axis as the independent variable. The band 6 correlation is also improved by ratioing with band 4 (figure 14). The MSS6/MSS4 ratio is linearly related to suspended solids in the region $\leq$ 100 ppm with an RMS residual of 19 ppm. The band 7 correlation, after ratioing with band 4, is not significantly improved (figure 15).

Figures 16, 17 and 18 lend additional support to the assumption that ratioing removes sun angle dependence. Band 4 (figure 16) and band 5 (figure 17) are strongly correlated with sun angle, whereas the band 5/band 4 ratio shows little or no correlation. The samples for this sun angle analysis were selected from the composite 13 month sample collection using the criteria that the suspended solids were in the range 25 to 45 ppm. This selection satisfied the combined requirements that enough data existed at each measured ERTS cycle and that the MSS ratio was restricted to a reasonably narrow range.

Although the bulk of the suspended solids measurements were $\leq$ 240 ppm, there were a few (samples collected upstream in the reservoir after a recent rain) that extended as high as 900 ppm. The next several figures display the complete data set over the range 0-900 ppm. The MSS5/MSS4 ratio (figure 19) rises sharply to ~ 80 ppm then turns

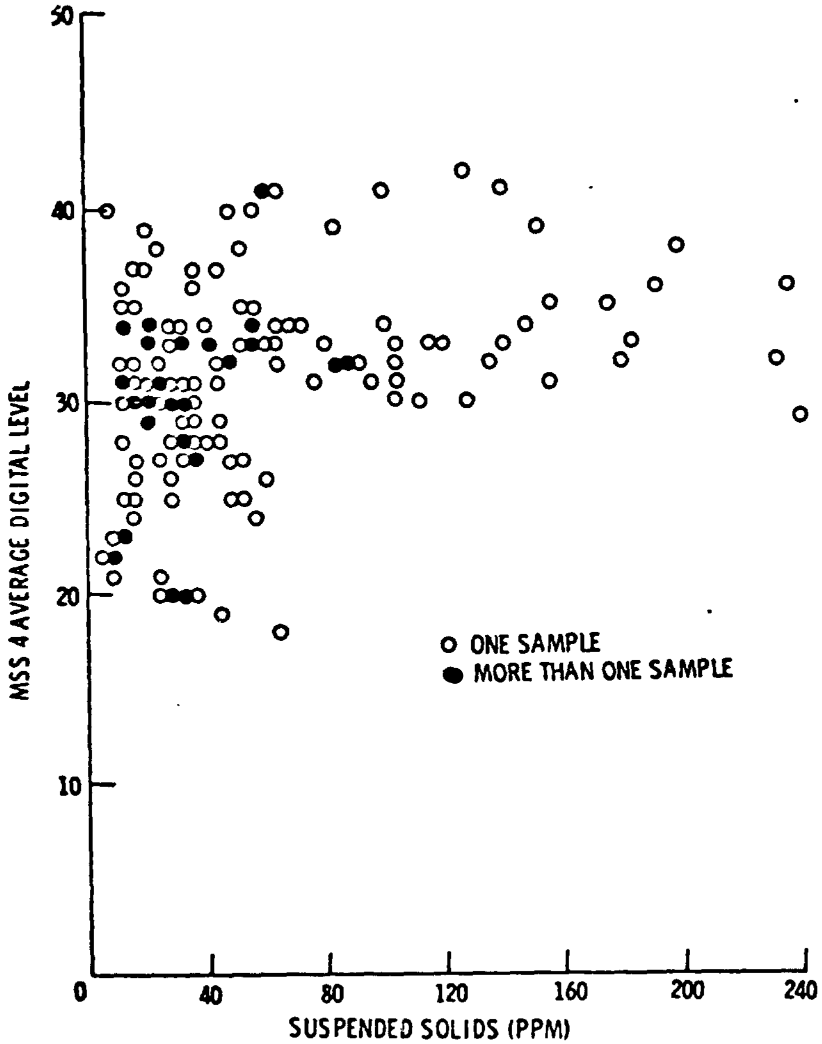


FIGURE 9. MSS 4 CCT DIGITAL LEVEL VS. SUSPENDED SOLIDS FOR 166 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

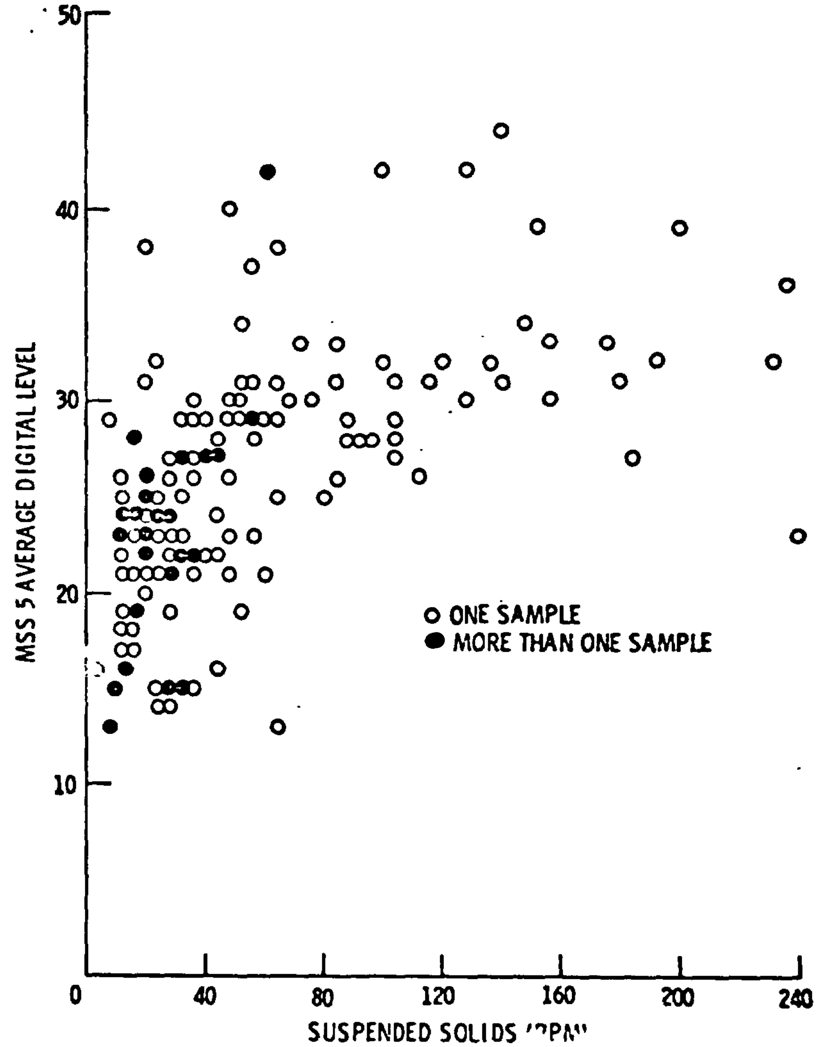


FIGURE 10. MSS 5 CCT DIGITAL LEVEL VS. SUSPENDED SOLIDS FOR 166 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

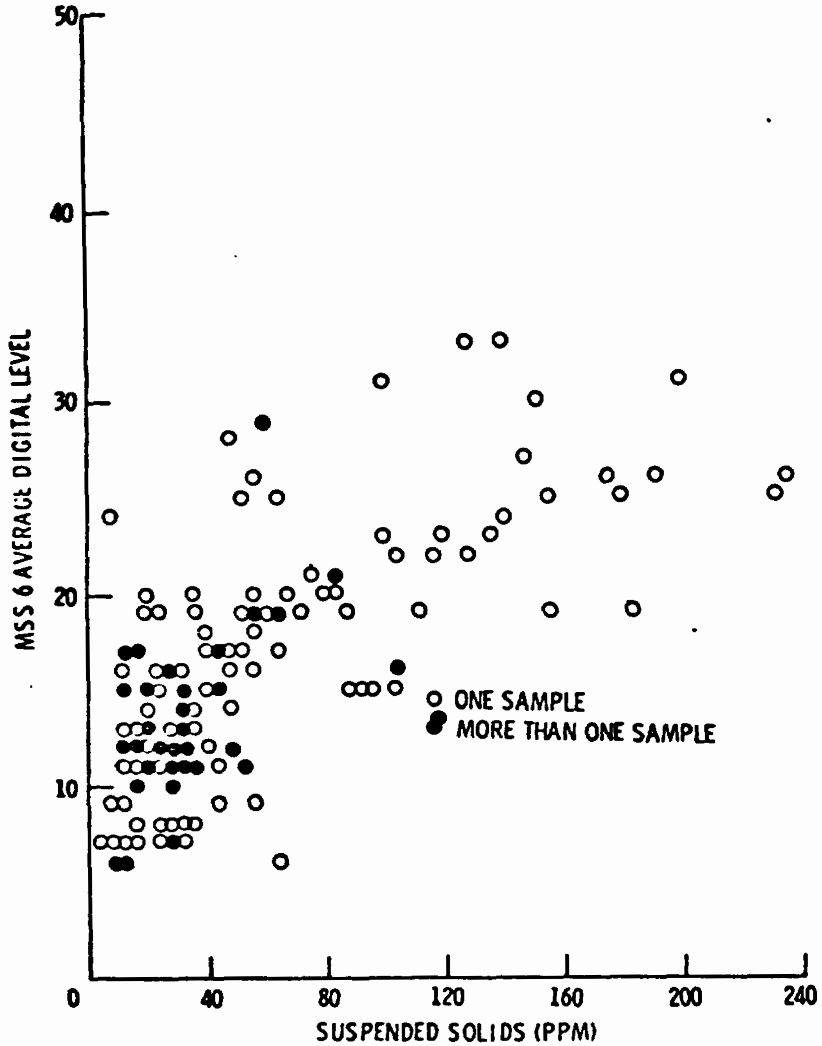


FIGURE 11. MSS 6 CCT DIGITAL LEVEL VS. SUSPENDED SOLIDS FOR 164 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFEPENT ERTS-1 CYCLES.

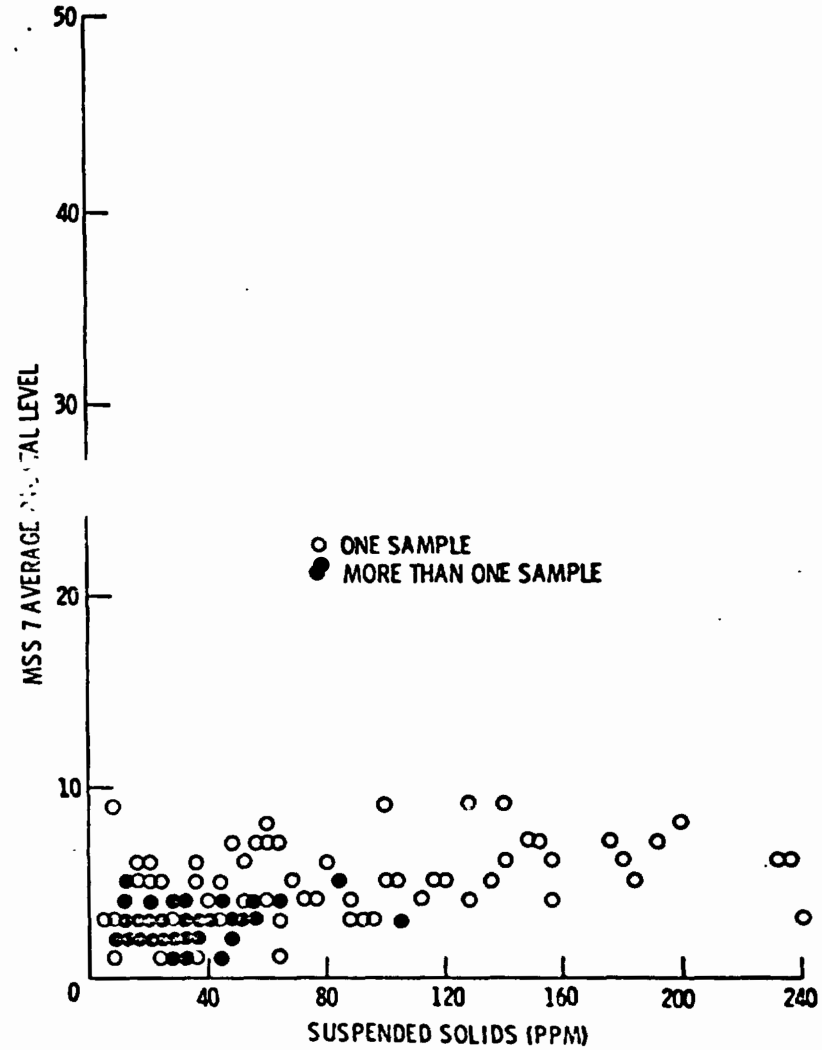


FIGURE 12. MSS 7 CCT DIGITAL LEVEL VS. SUSPENDED SOLIDS FOR 165 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1CYCLES.

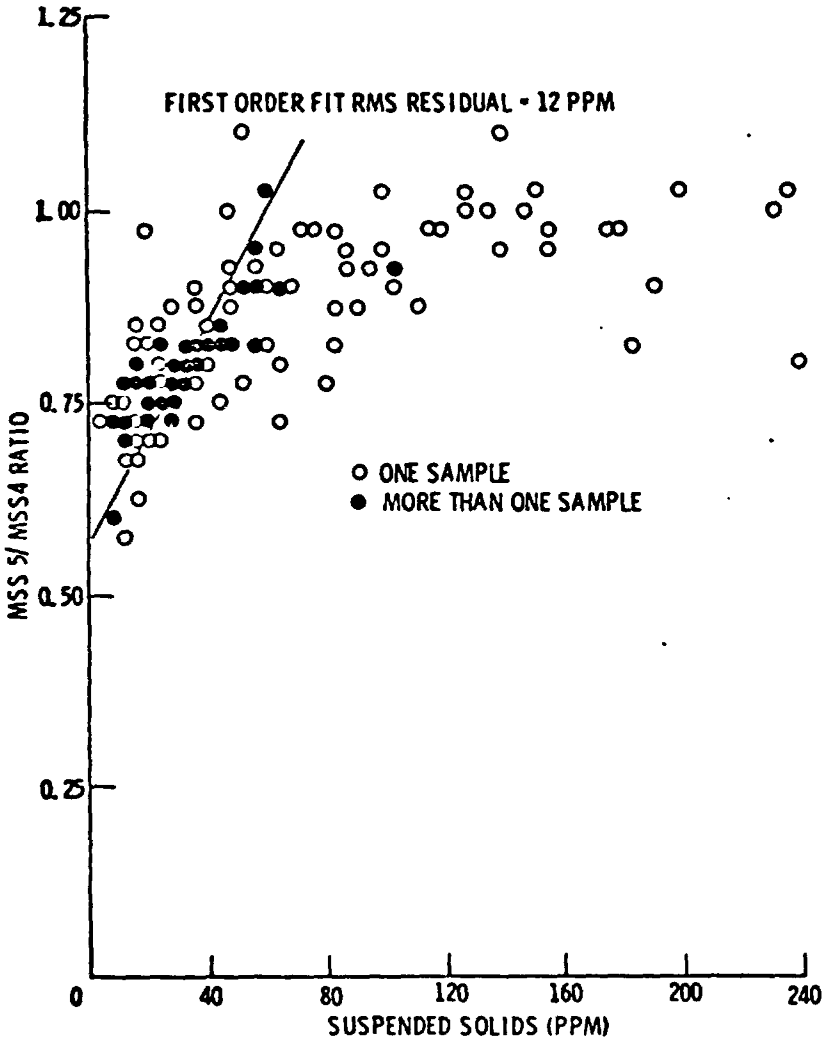


FIGURE 13. MSS 5/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 167 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

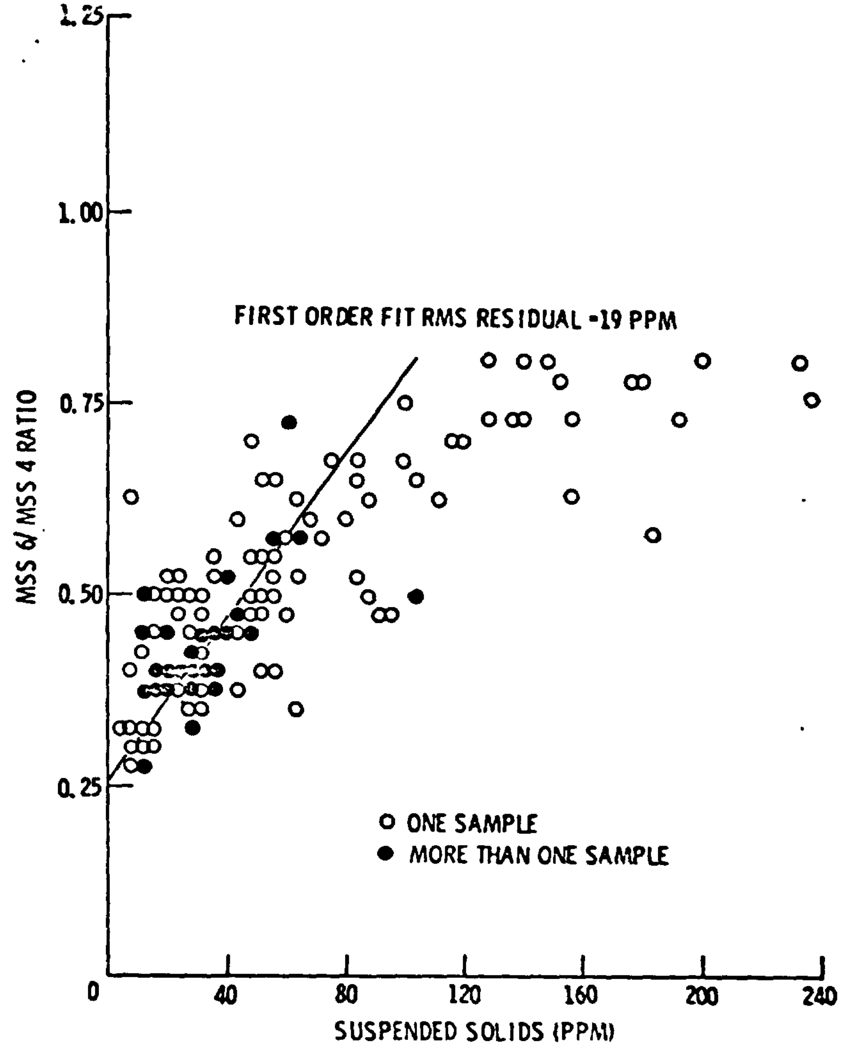


FIGURE 14. MSS6/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 166 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

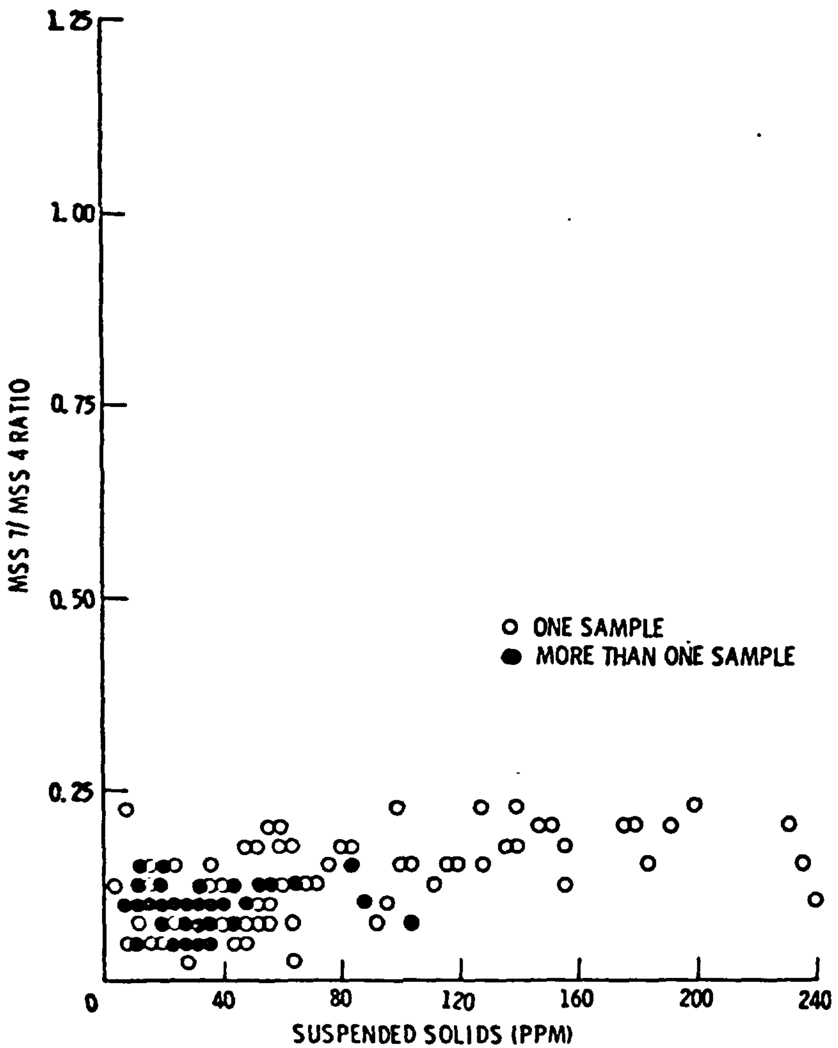


FIGURE 15. MSS 7/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 167 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

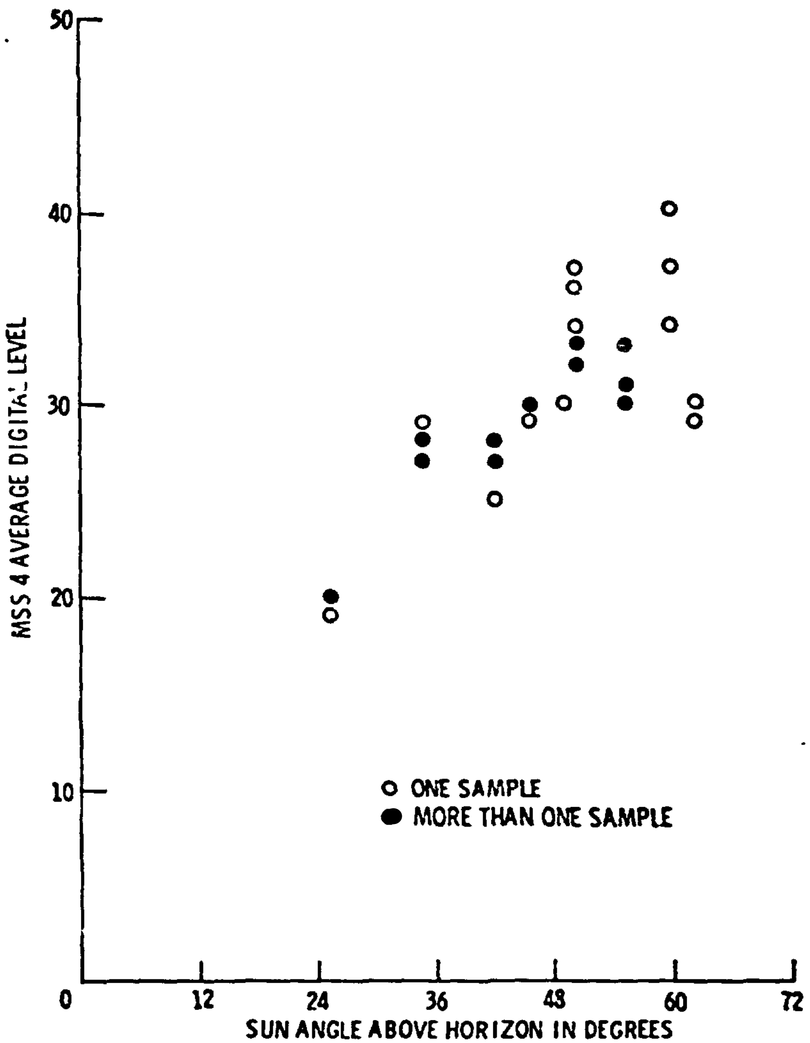


FIGURE 16. MSS 4 CCT DIGITAL LEVEL VS. SUN ANGLE FOR SAMPLES BETWEEN 25 AND 45 PPM IN FIG. 9.

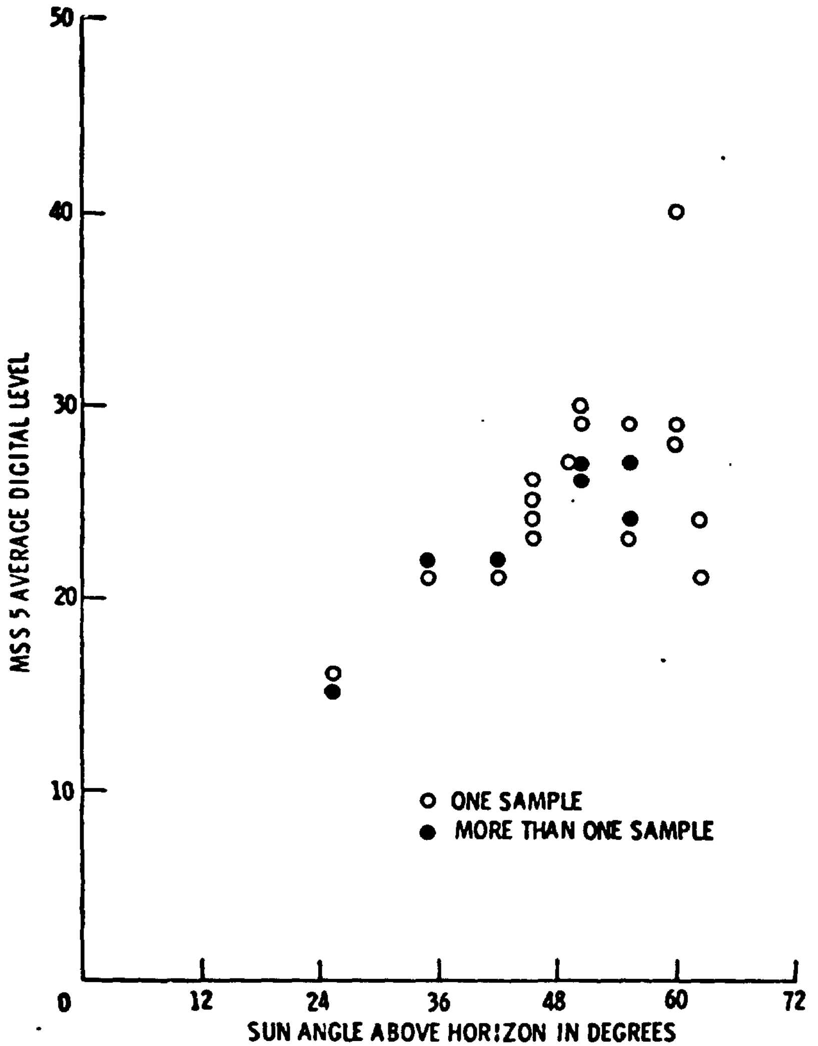


FIGURE 17. MSS 5 CCT DIGITAL LEVEL VS. SUN ANGLE FOR SAMPLES BETWEEN 25 AND 45 PPM IN FIG. 10.

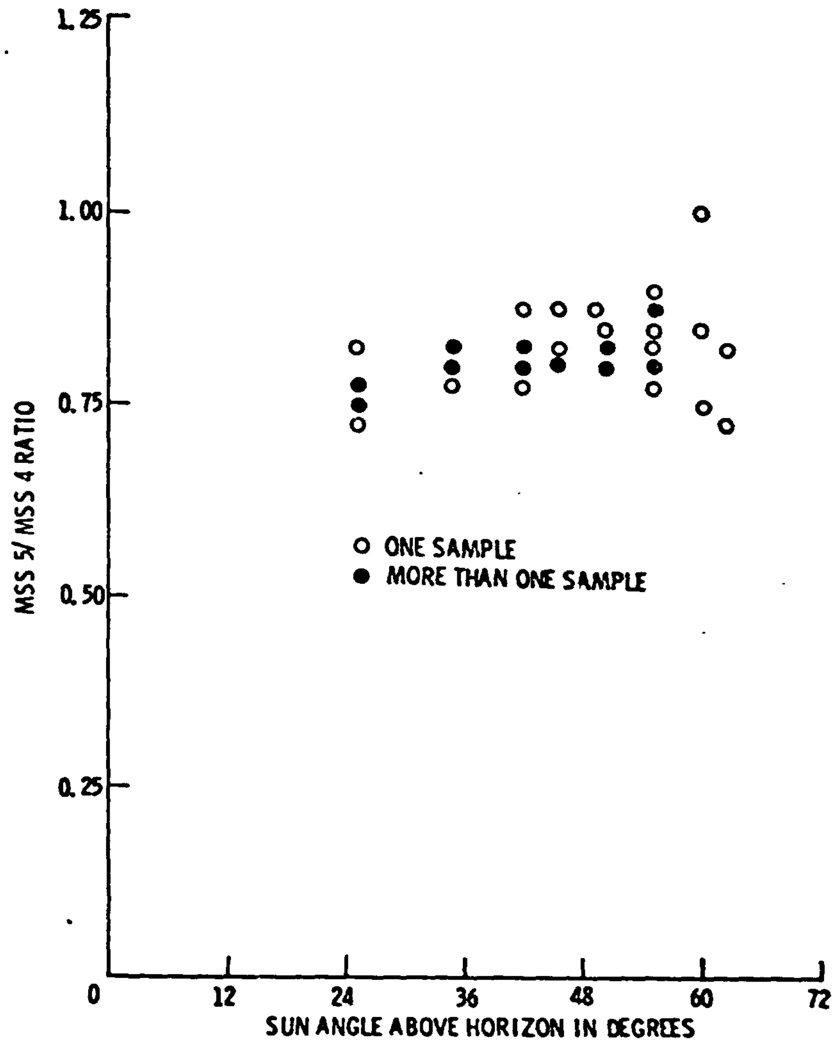


FIGURE 18. MSS 5/MSS 4 CCT RATIO VS. SUN ANGLE FOR SAMPLES BETWEEN 25 AND 45 PPM IN FIG. 13.

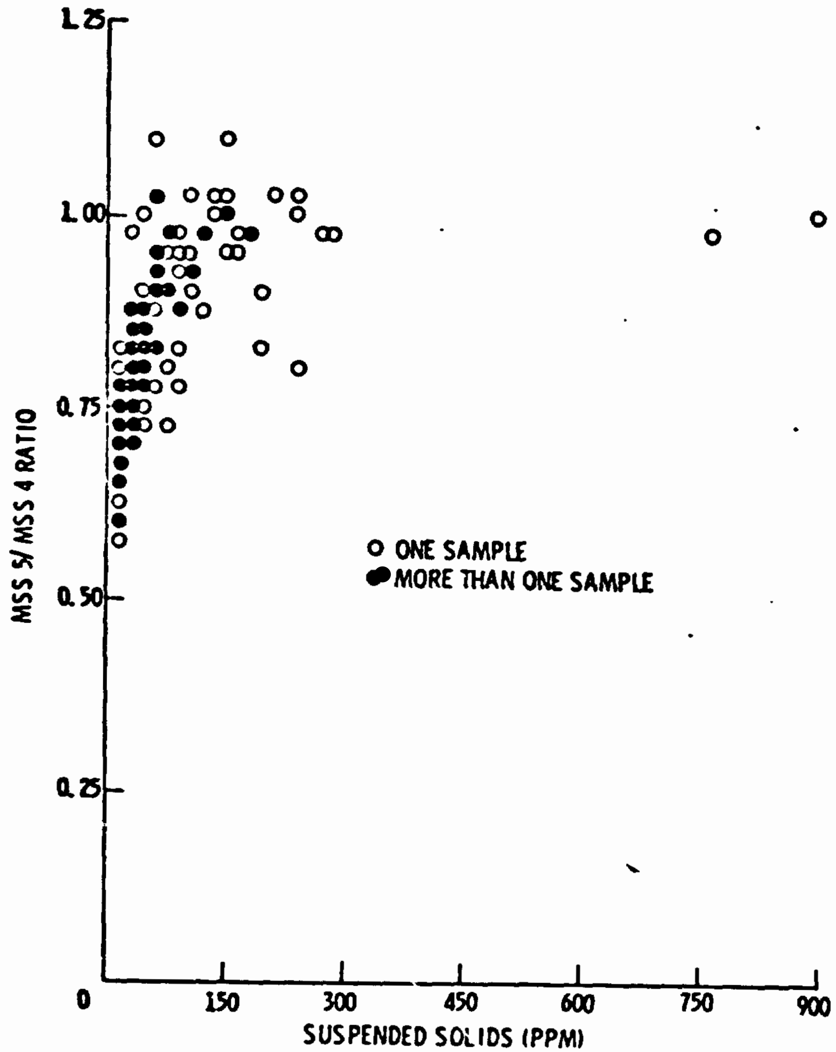


FIGURE 19. MSS 5/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

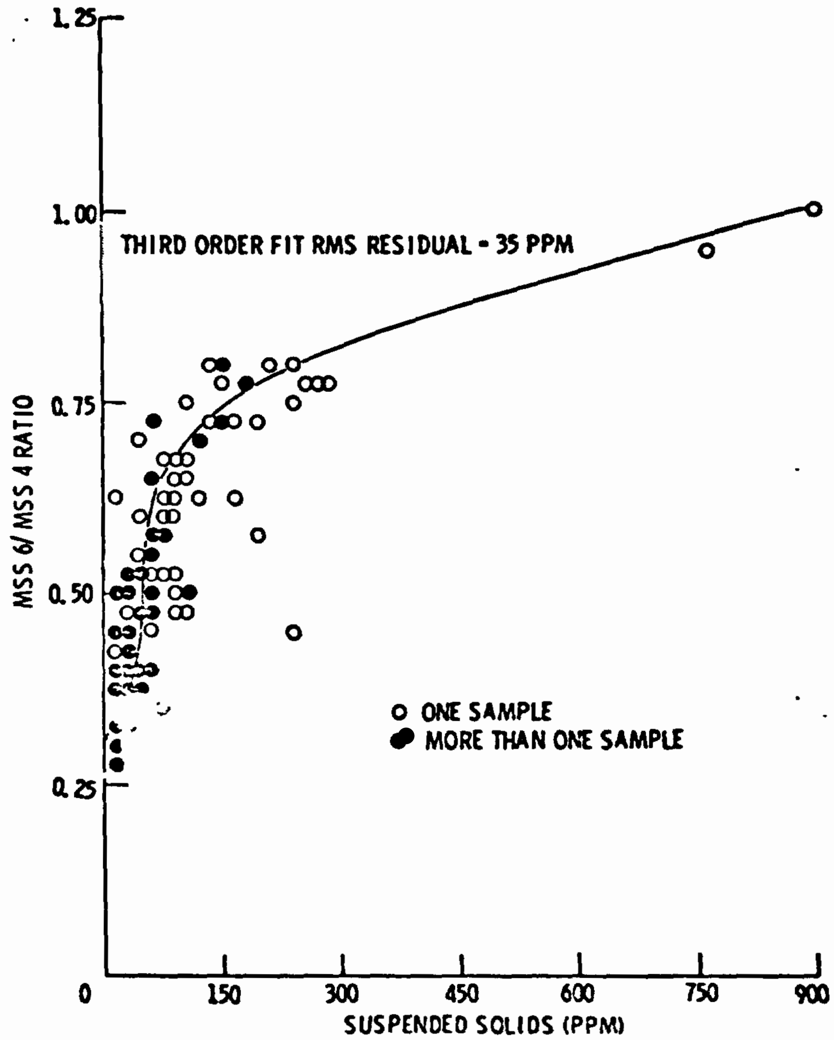


FIGURE 20. MSS 6/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 170 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

over and remains flat up to 900 ppm which is the limit of this investigation. The MSS6/MSS4 ratio (figure 20) rises sharply to ~120 ppm then turns over, but continues to correlate well with suspended solids up to 900 ppm. It appears that this correlation would continue well beyond 900 ppm. A smooth polynominal fit over the range 0-900 ppm yields an RMS residual of 35 ppm. Band 7/Band 4 (figure 21) also shows correlation up to 900 ppm with an RMS residual of 44 ppm. As can be seen by comparing figures 12 and 15, ratioing band 7 with band 4 does not appear to improve the band 7 correlation with suspended solids. Ratioing does, however, improve the RMS residual by several ppm over the range 0-900 ppm. Since band 7 is nowhere near maximum reflection at 900 ppm it is expected this band would continue to correlate up to extremely high suspended loads.

Figure 22 summarizes the correlations between the three MSS ratios and suspended solids. The regression coefficients can be used to predict suspended load from CCT digital levels. MSS5/MSS4 is effective in the range 0-80 ppm with accuracy of 12 ppm. MSS6/MSS4 is effective in the range 0-120 or 0-900 ppm with accuracies of 19 and 35 ppm respectively. MSS7/MSS4 is useful over the range 0-900 ppm with 44 ppm accuracy. It appears that the regression coefficients for MSS6/MSS4 and MSS7/MSS4 fits would be applicable substantially beyond 900 ppm, although this is not confirmed experimentally.

Figure 23 is an example of a suspended solids contour maps which was produced, in an earlier stage of this study, using regression coefficients that related band 5 to suspended solids. The coefficients were derived from four nearly equal high sun angle cycles which yielded an RMS residual of 5 ppm. In this particular case, ratioing was not required, since the correlation was based on nearly equal sun angle cycles.

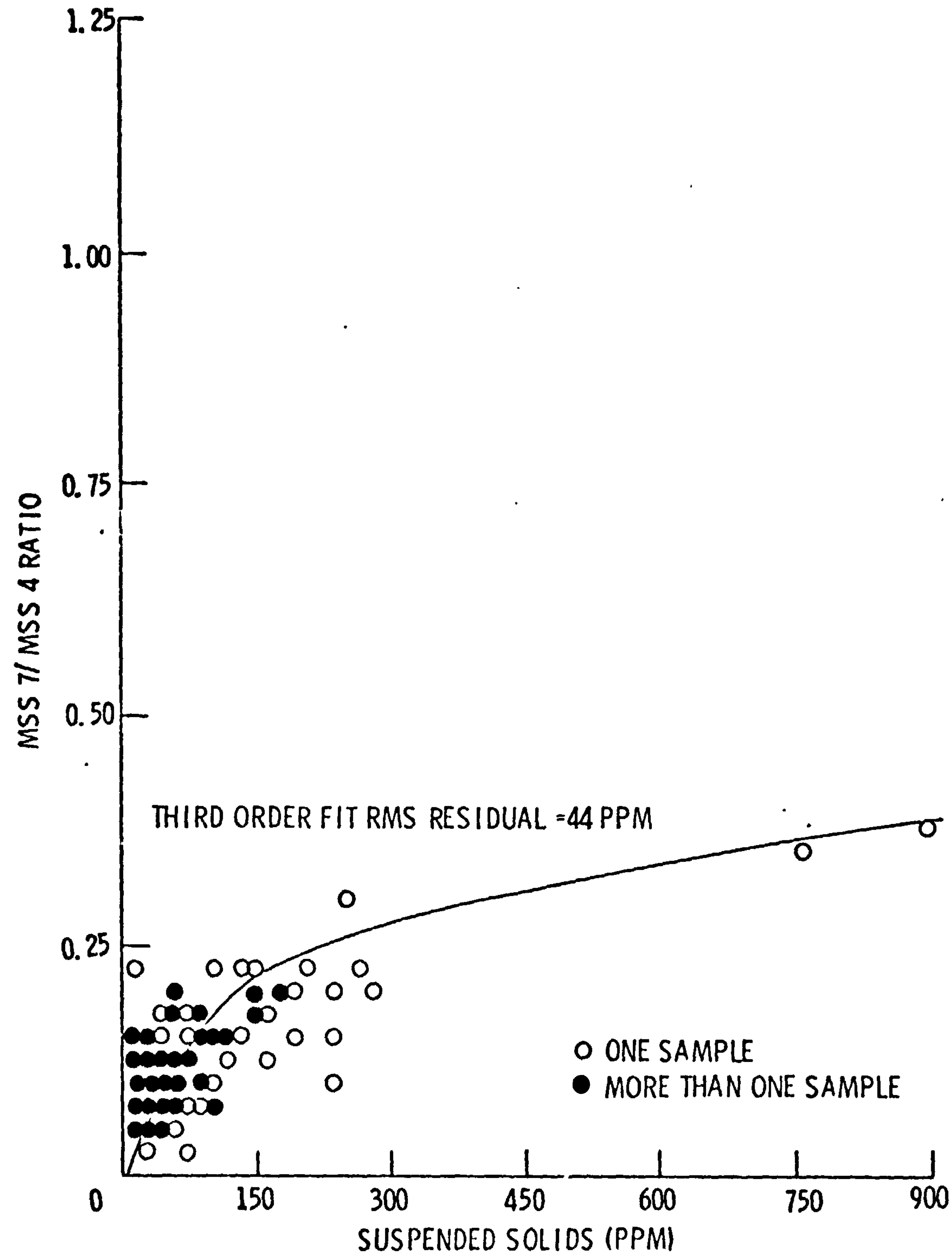


FIGURE 21. MSS 7/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

MSS BAND RATIO	RANGE OF APPLICABILITY IN PPM	RMS RESIDUAL IN PPM	$a_0 \times 10^{-2}$	$a_1 \times 10^{-2}$	$a_2 \times 10^{-2}$	$a_3 \times 10^{-2}$
R_{54}	0-80	12	-0.793	1.387	-	-
R_{64}	0-120	19	-0.426	1.768	-	-
R_{64}	0-900	35	-6.403	42.598	-89.112	62.373
R_{74}	0-900	44	0.090	5.580	-43.879	254.654

FIGURE 22. RESULTS OF FITTING SUSPENDED SOLIDS MEASUREMENTS TO CCT MSS BAND RATIOS. EQUATION USED IN FIT WAS $SS = a_0 + a_1 R_{ij} + a_2 R_{ij}^2 + a_3 R_{ij}^3$ WHERE SS = SUSPENDED SOLIDS (PPM) AND R_{ij} = ($BAND_i$ AVERAGE CCT LEVEL FOR 9 PIXELS)/($BAND_j$ AVERAGE CCT LEVEL FOR 9 PIXELS). THE FITTED CURVES ARE SHOWN IN FIGURES 13, 14, 20 AND 21.

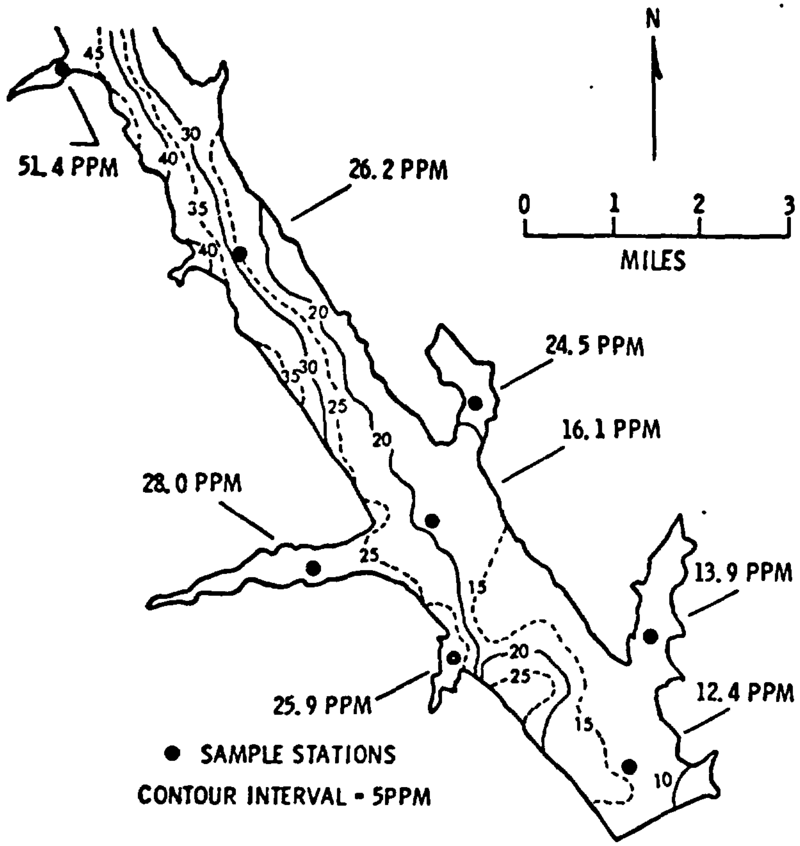


FIGURE 23. SUSPENDED SOLIDS CONTOUR MAP OF TUTTLE CREEK RESERVOIR (AUGUST 14, 1972 ERTS-1 ID NO. 1022-16391-5) DERIVED FROM CCTS (MSS 5) FOR 4 ERTS-1 PASSES.

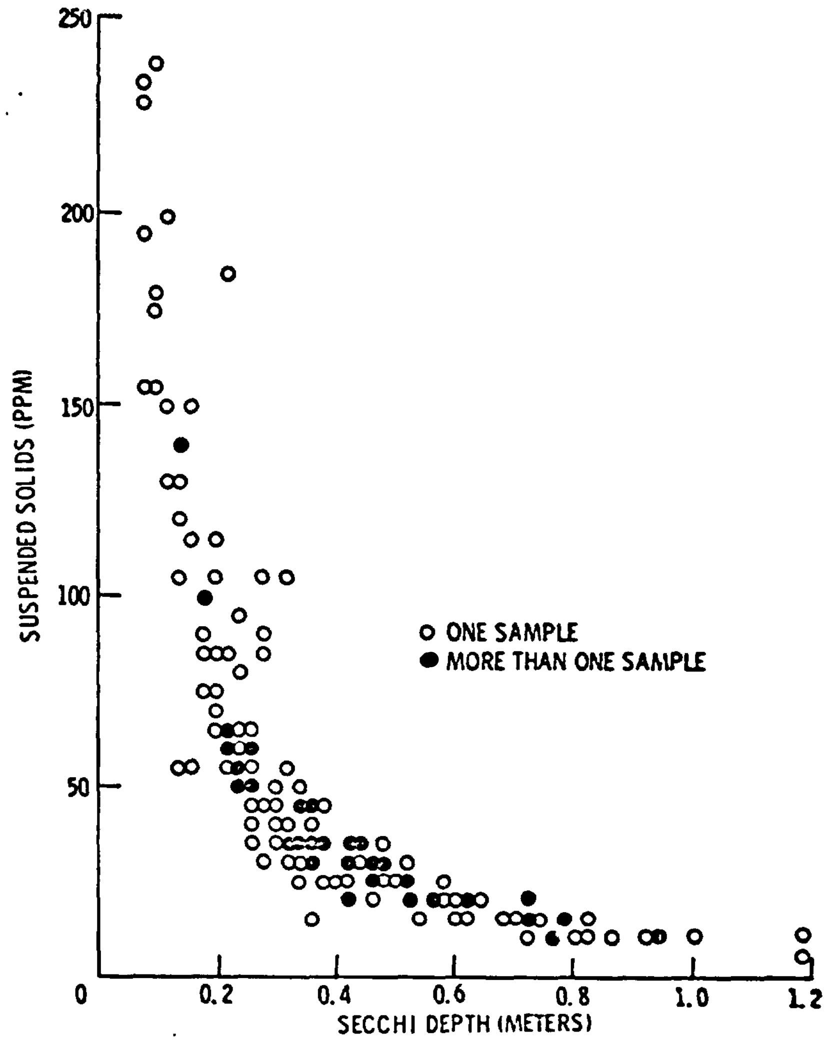


FIGURE 24. SUSPENDED SOLIDS VS. SECCHI DEPTH FOR 168 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

5.0 SECCHI DEPTH

The analysis in section 4.0 establishes that suspended solids in water are strongly correlated with reflected energy present in the four MSS bands. Figure 24 shows that secchi depth (or water clarity) is well correlated with suspended solids measurements $\gtrsim 15$ ppm which represents the bulk of the data in this study. The points in figure 24 appear to describe a hyperbolic curve and consequently fall on a straight line when suspended solids are plotted against inverse secchi depth (figure 25). Linear regression yields an RMS residual of 18 ppm, so that a secchi depth measurement can be used to determine suspended load to this level of accuracy.

The MSS5/MSS4 ratio is linearly correlated with secchi depth $\lesssim 0.6$ meters (figure 26), with RMS residual of 0.11 meters, which is merely a reflection of the fact that secchi depth is correlated with suspended solids $\gtrsim 15$ ppm. Beyond 0.6 meters ($\lesssim 15$ ppm), where this ratio is not well correlated with suspended solids, the ratio correlation with secchi depth is much weaker, but still appears to decline slightly for increasing depths. MSS correlation with sunlight penetration depth in relatively clear ocean water has been found by other workers (Polcyn, 1973) and used to map ocean bottom to depths of 10 meters.

MSS6/MSS4 correlates with secchi depth down to ~ 0.4 meters with RMS residual 0.06 meters. The correlation at shallow depths $\lesssim 0.2$ meters is improved over the MSS5/MSS4 correlation. This is expected since this secchi depth range corresponds to suspended solids $\gtrsim 80$ ppm (see figure 24) where MSS5/MSS4 is poorly correlated. MSS7/MSS4 correlates with secchi depth up to ~ 0.3 meters with RMS residual of 0.05 meters.

In summary, secchi depth correlates well with MSS ratios in relatively turbid water (suspended solids ≥ 15 ppm), but is primarily a reflection of the fact that secchi depth is correlated with suspended solids. Nevertheless, MSS ratios are useful for direct prediction of water clarity (secchi depth). Figure 29 summarizes the results of the regression analysis.

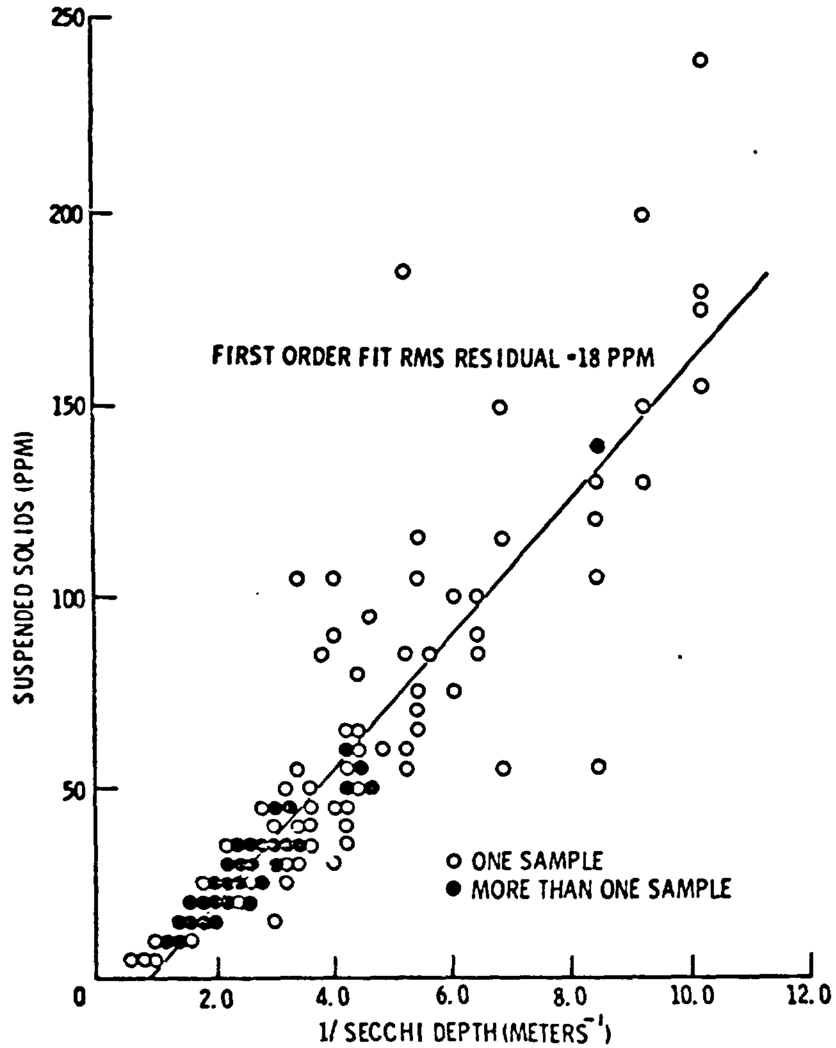


FIGURE 25. SUSPENDED SOLIDS VS. INVERSE SECCHI DEPTH FOR 164 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

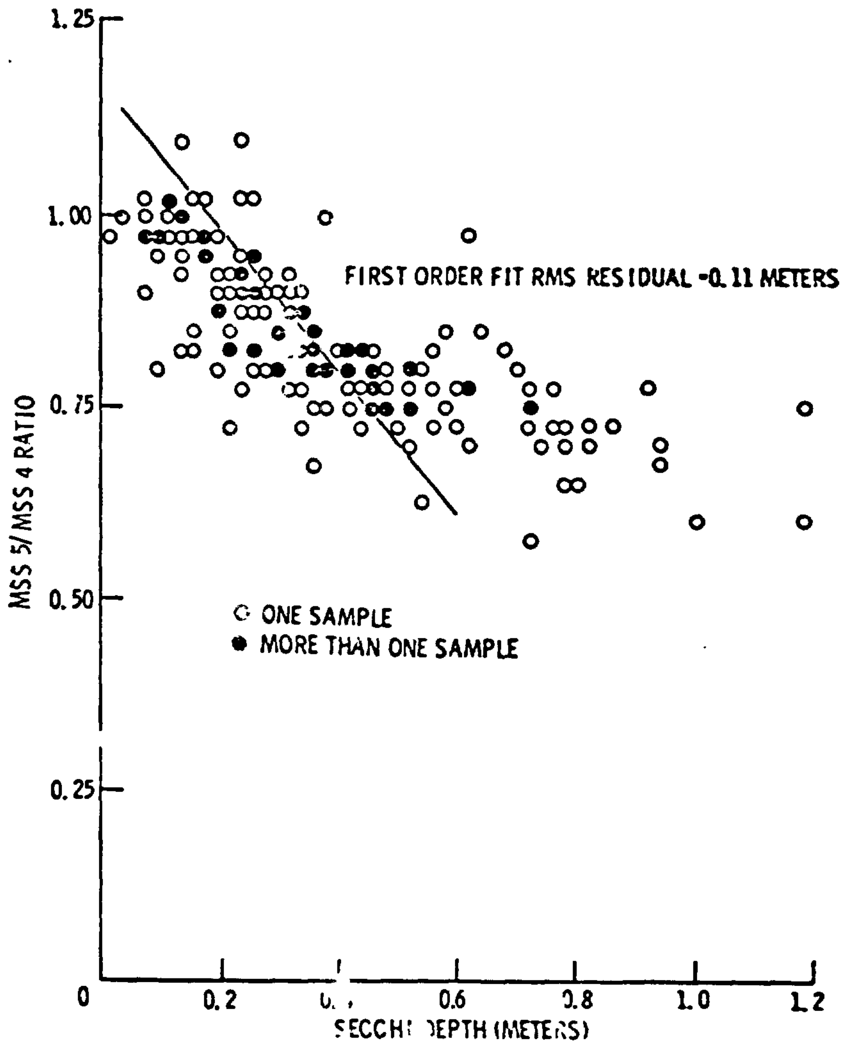


FIGURE 26. MSS 5/MSS 4 CC. RATIO VS. SECCHI DEPTH FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

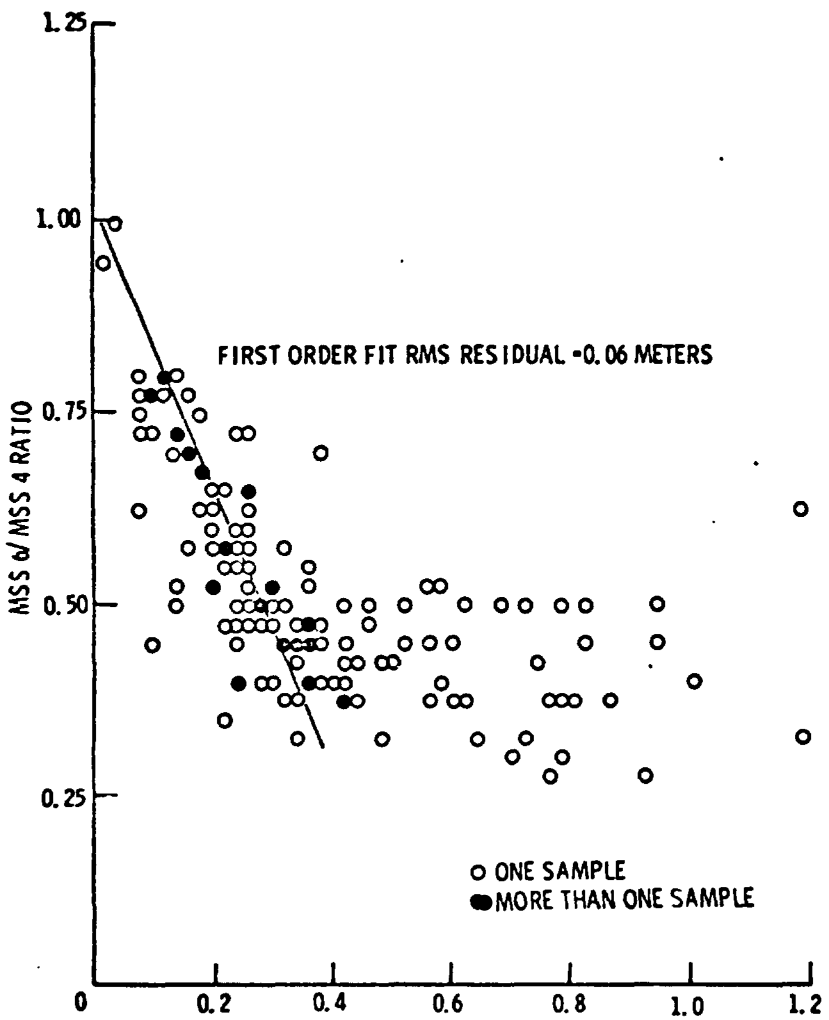


FIGURE 27. MSS 6/MSS 4 CCT RATIO VS. SECCHI DEPTH FOR 170 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

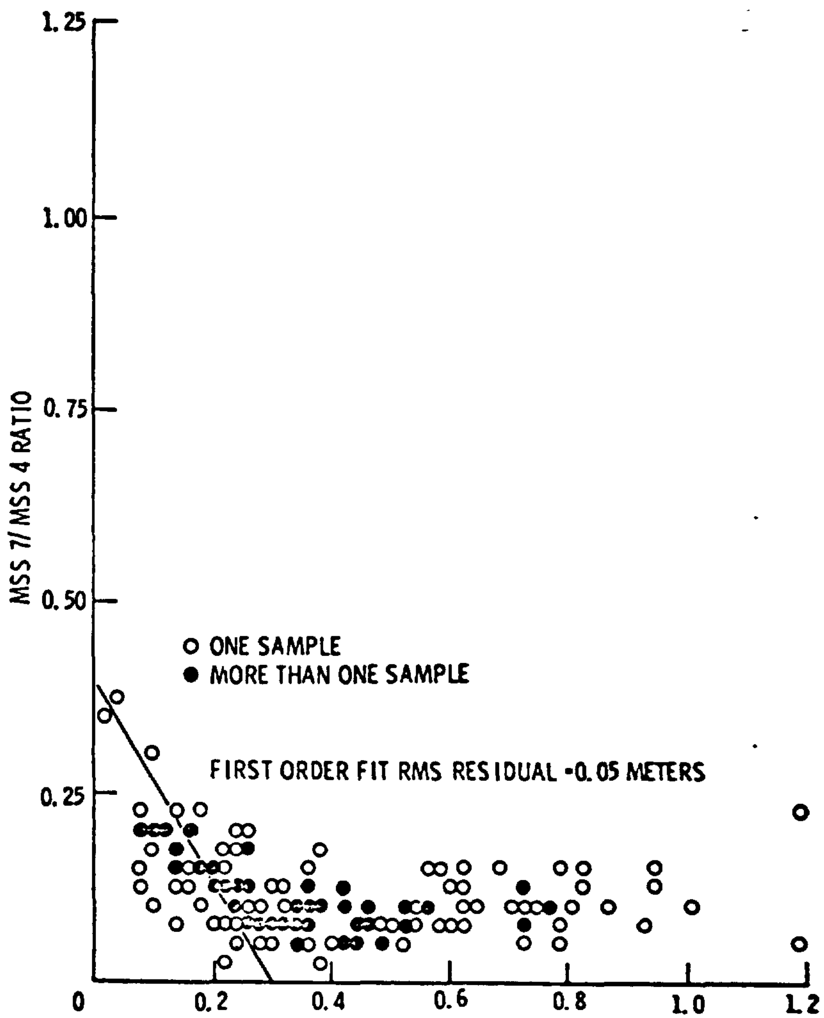


FIGURE 28. MSS 7/MSS 4 CCT RATIO VS. SECCHI DEPTH FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT ERTS-1 CYCLES.

MSS BAND RATIO	RANGE OF APPLICABILITY IN METERS	RMS RESIDUAL IN METERS	a_0	a_1
R_{54}	0-0.70	0.11	1.210	-1.061
R_{64}	0-0.40	0.06	0.526	-0.529
R_{74}	0-0.30	0.05	0.278	-0.727

FIGURE 29. RESULTS OF FITTING SECCHI DEPTH MEASUREMENTS TO CCT MSS BAND RATIOS. EQUATION USED IN FIT WAS $SD = a_0 + a_1 R_{ij}$ WHERE SD = SECCHI DEPTH (METERS) AND R_{ij} = ($BAND_i$ AVERAGE CCT LEVEL FOR 9 PIXELS)/($BAND_j$ AVERAGE CCT LEVEL FOR 9 PIXELS). THE FITTED LINES ARE SHOWN IN FIGURES 26, 27, AND 28.

6.0 WIND AND TEMPERATURE EFFECTS

An average wind velocity for each ERTS reservoir cycle was recorded along with a temperature measurement at each sample station. The three MSS ratios show no systematic correlation with wind speed (see figure 30 for MSS5/MSS4 example) up to 21 miles/hour. As expected from previous laboratory work on distilled water (Scherz, 1971) the MSS ratios exhibit no correlation with water temperature (figure 31).

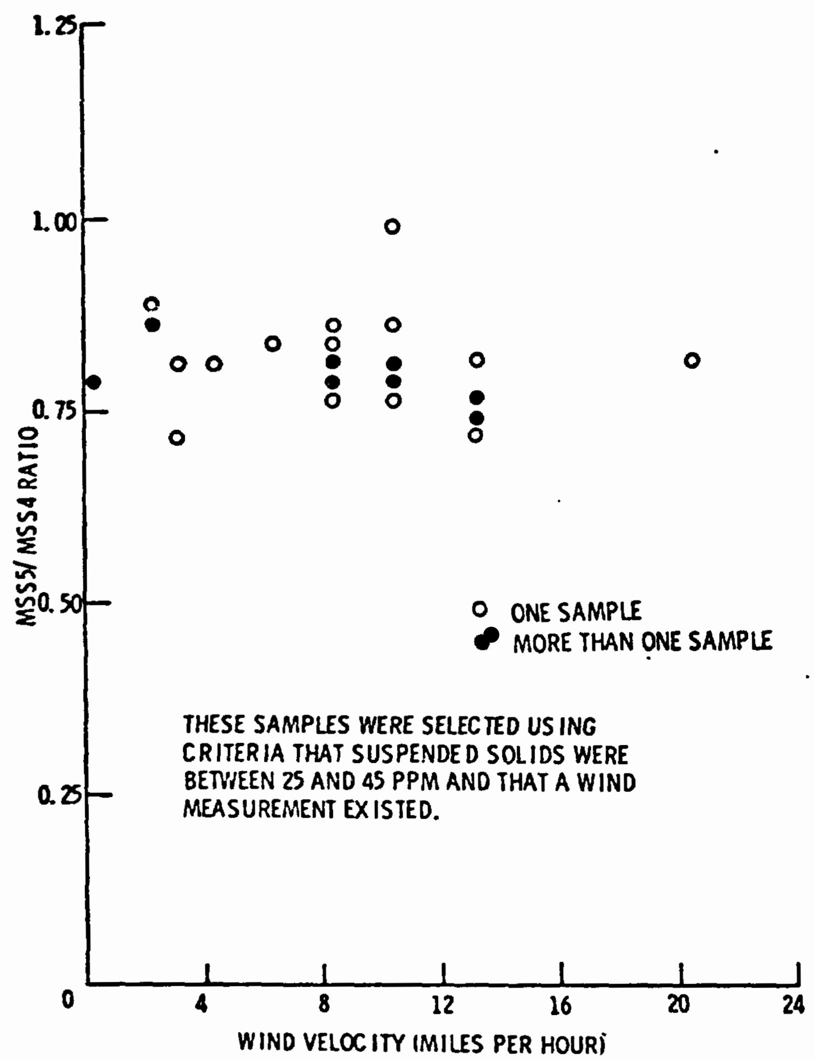


FIGURE 30. MSS 5/MSS 4 CCT RATIO VS. WIND VELOCITY FOR 35 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

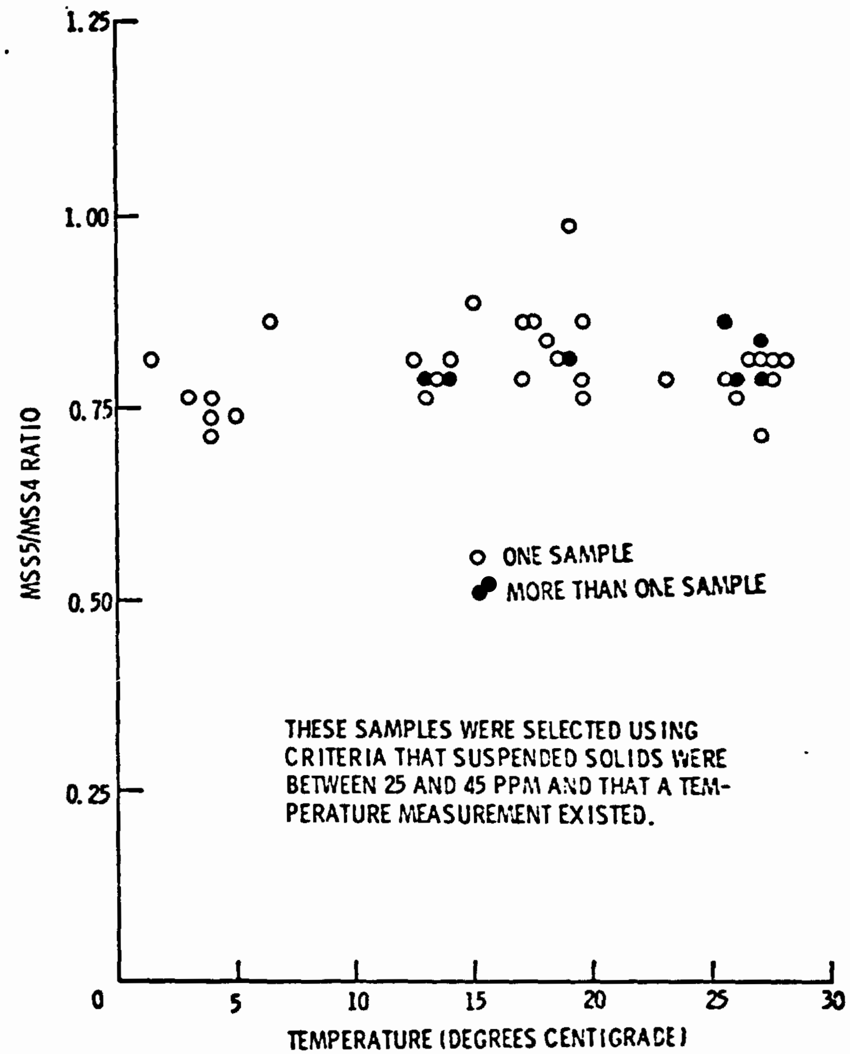


FIGURE 31. MSS 5/MSS 4 CCT RATIO VS. TEMPERATURE FOR 44 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

7.0 ORGANIC AND DISSOLVED SOLIDS

The character of the sediment carried into Tuttle Creek and Perry reservoirs can be summarized as follows. The lower part of the Blue River basin, which drains into Tuttle Creek, consists mainly of residual and alluvial soils derived from shales and limestones. The upper portion has loessial soils underlain by glacial tills and alluvial sands. The average particle size of the bottom sediment is 2 microns (Schwartz and Marzolf, 1971). The suspended sediment consists mostly of the three clays vermiculite, illite and kaolinite. Perry reservoir drains a basin consisting mostly of loessial soils underlain by glacial tills. Perry is generally not as turbid as Tuttle Creek, but its suspended sediment is very similar in mineralogy and degree of aggregation.

The following characterizes the composite sample set collected over a 13 month period from three reservoirs. The bulk of the samples contain total solids in the range 200 to 500 ppm. The suspended sediment fraction of the total solids ranges from 2 to 50%. The organic fraction of the suspended sediment is almost constant at 14% and is thus highly correlated with total suspended solids (figure 32). Consequently, the MSS ratio correlation with organic suspended load (not shown) is merely a reflection of the MSS ratio dependence on total suspended load.

The dissolved solids fraction of total solids ranges from 50 to 98% which is, of course, the compliment of the suspended solids fraction. The organic fractions of dissolved solids range from 10 to 50%. The dissolved solids appear to be uncorrelated with suspended solids (figure 33), so that this experiment should be able to detect any appreciable influence dissolved solids have on reflected energy levels in the MSS bands. However, MSS5/MSS4 does not show any obvious correlation with dissolved solids (figure 34). The subset of data in figure 34 which has suspended solids >80 ppm is displayed in figure 35. Since the MSS5/MSS4 ratio does not vary for suspended solids > 80 ppm, any dissolved solids influence on the ratio should be more easily detectable in figure 35. As can be seen, there is a slight ratio decline with increasing dissolved solids, but the correlation is not strong enough to be useful over this range of suspended solids.

The compliment, i.e. samples with suspended solids < 80 ppm, to the data in figure 35 is shown in figure 36. The residual MSS5/MSS4 ratio, obtained by subtracting the linear dependence on suspended solids, is plotted against dissolved solids. The MSS5/ MSS4 linear dependence on suspended solids (for samples with suspended solids < 80 ppm) was determined by a regression of the MSS ratio against suspended solids. This fit is slightly different than the one shown in figure 13 which was obtained by a regression

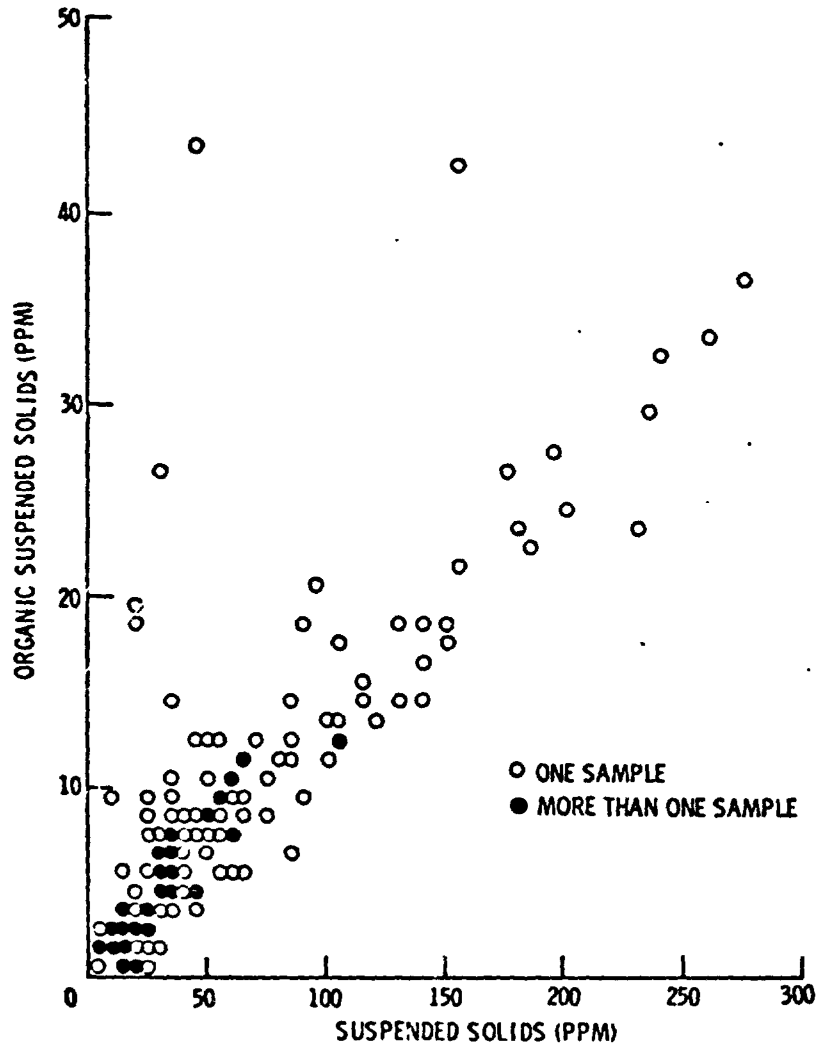


FIGURE 32. ORGANIC SUSPENDED SOLIDS VS. SUSPENDED SOLIDS FOR 120 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

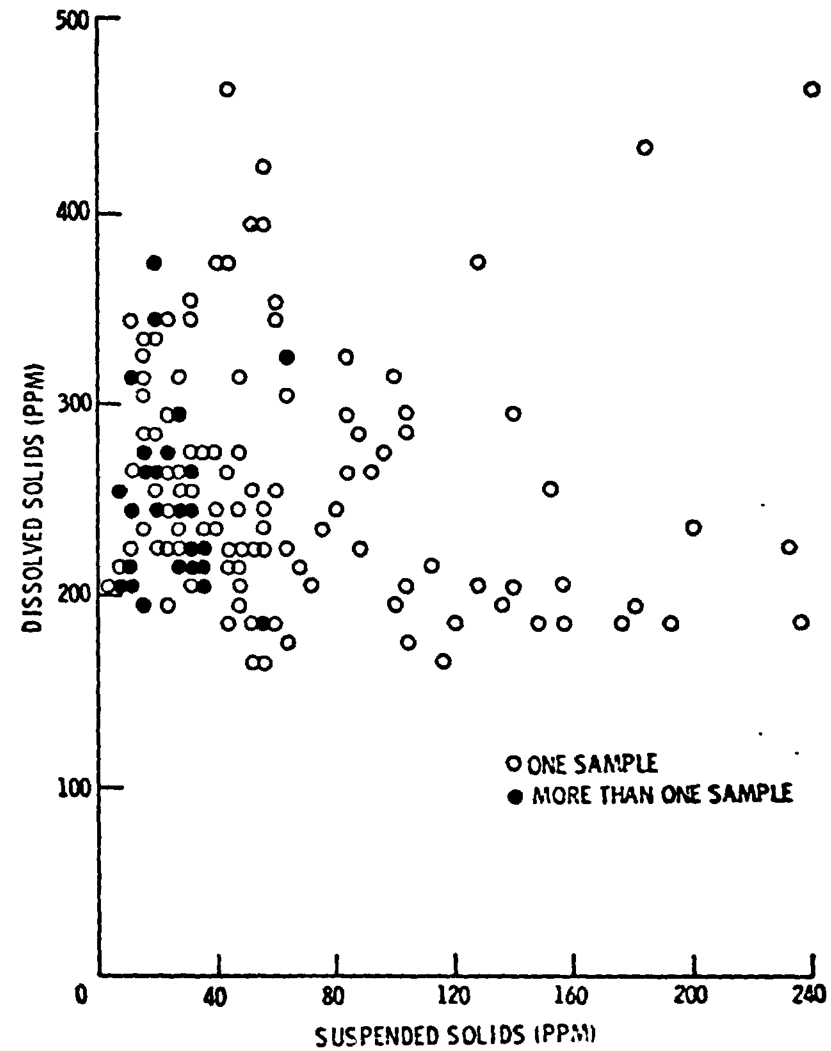


FIGURE 33. DISSOLVED SOLIDS VS. SUSPENDED SOLIDS FOR 120 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

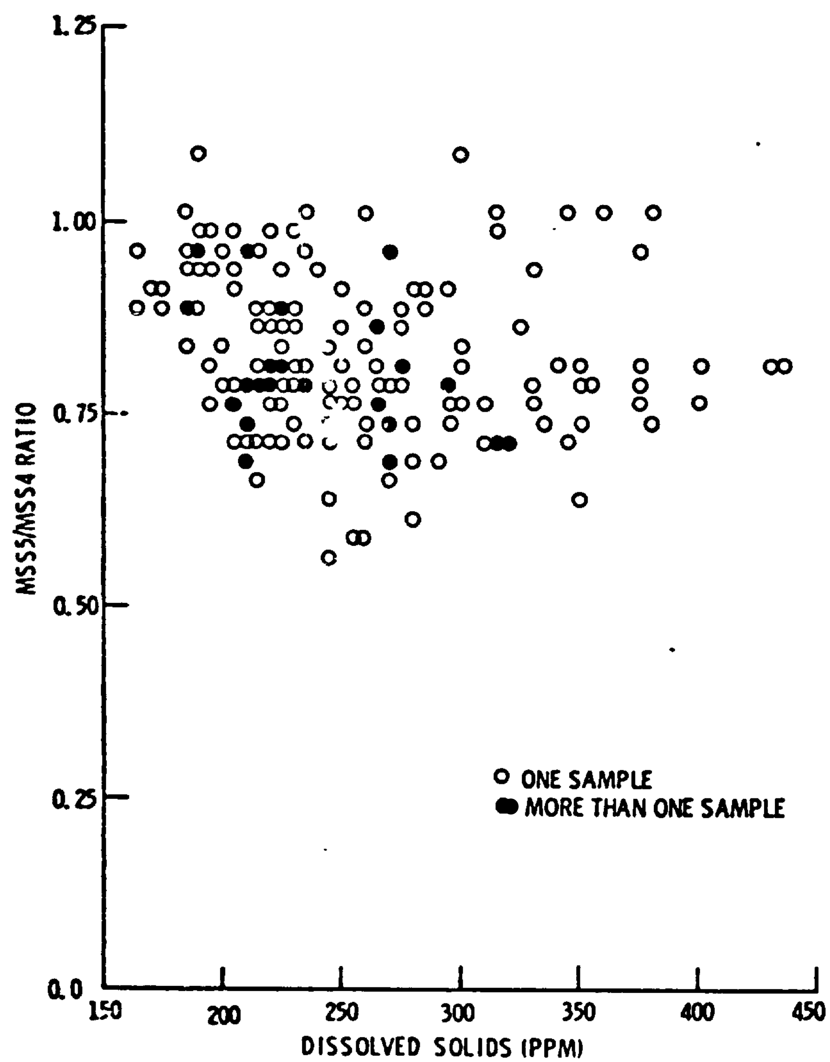


FIGURE 34. MSS 5/MSS 4 CCT RATIO VS. DISSOLVED SOLIDS FOR 120 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

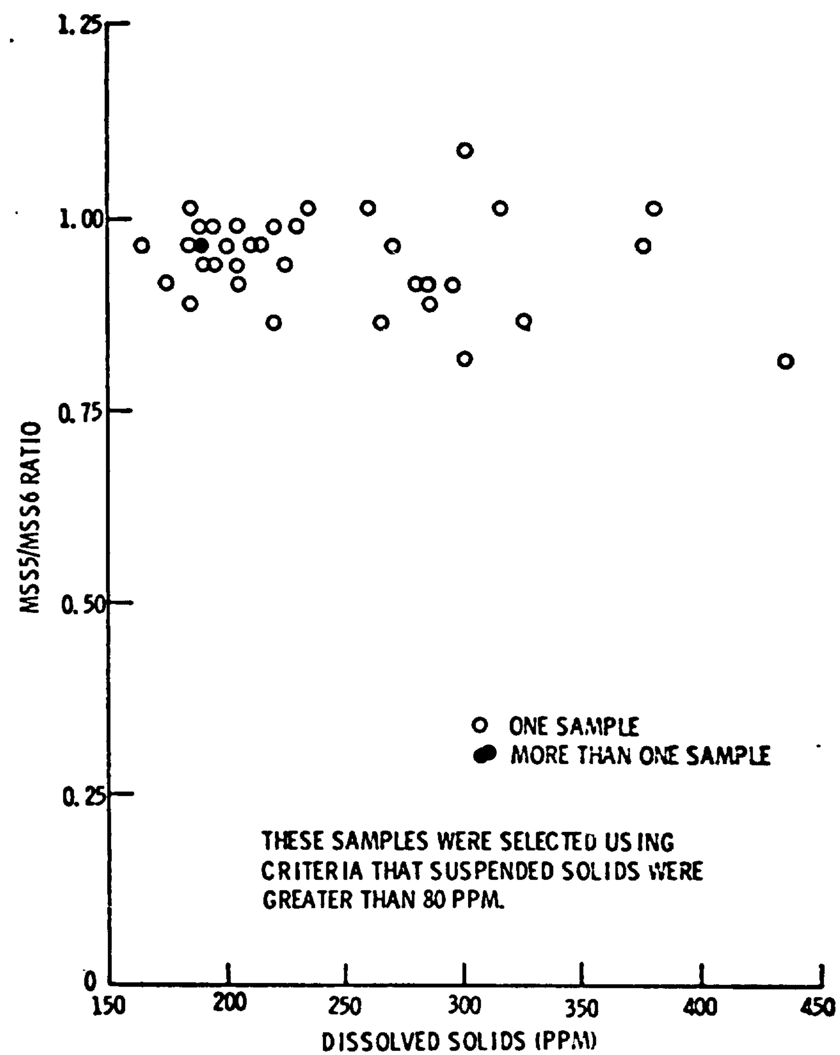


FIGURE 35. MSS 5/MSS 4 CCT RATIO VS. DISSOLVED SOLIDS FOR 38 SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

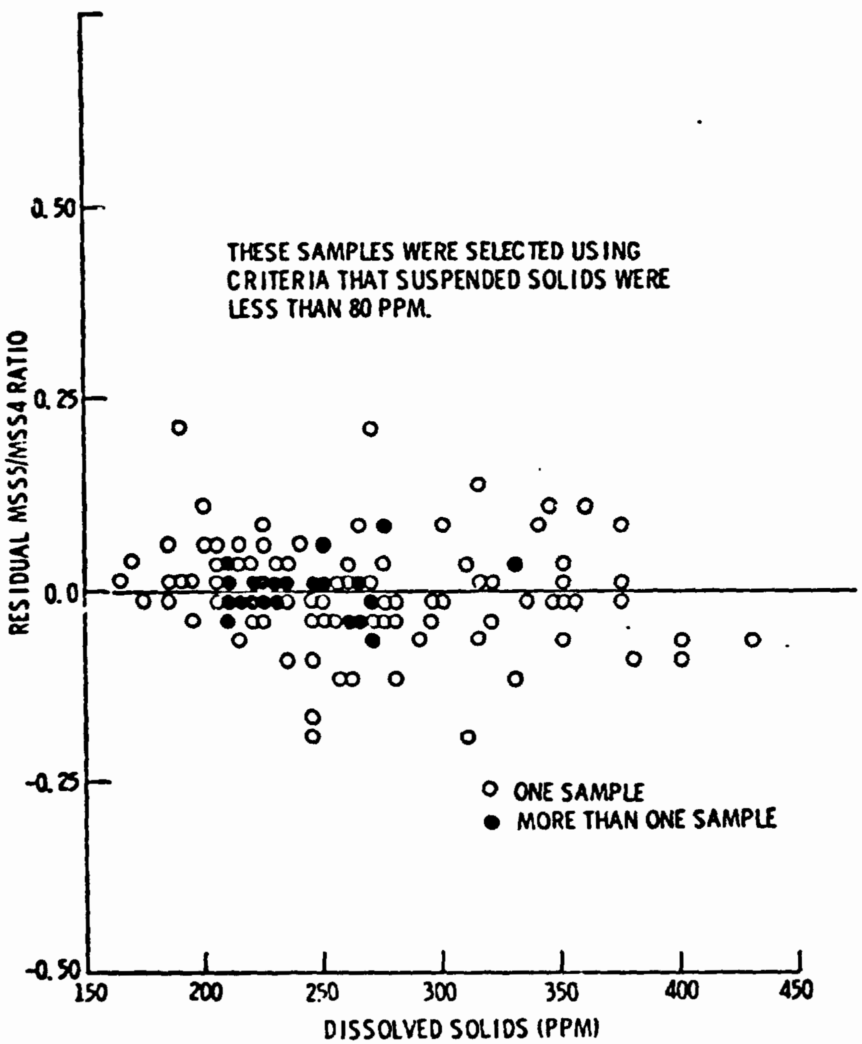


FIGURE 36. RESIDUAL MSS 5/MSS 4 CCT RATIO VS. DISSOLVED SOLIDS FOR 133 SAMPLES TAKEN FROM 3 RESERVOIRS OVER A 13 MONTH PERIOD. RESIDUAL WAS OBTAINED BY SUBTRACTING LINEAR DEPENDENCE ON SUSPENDED SOLIDS.

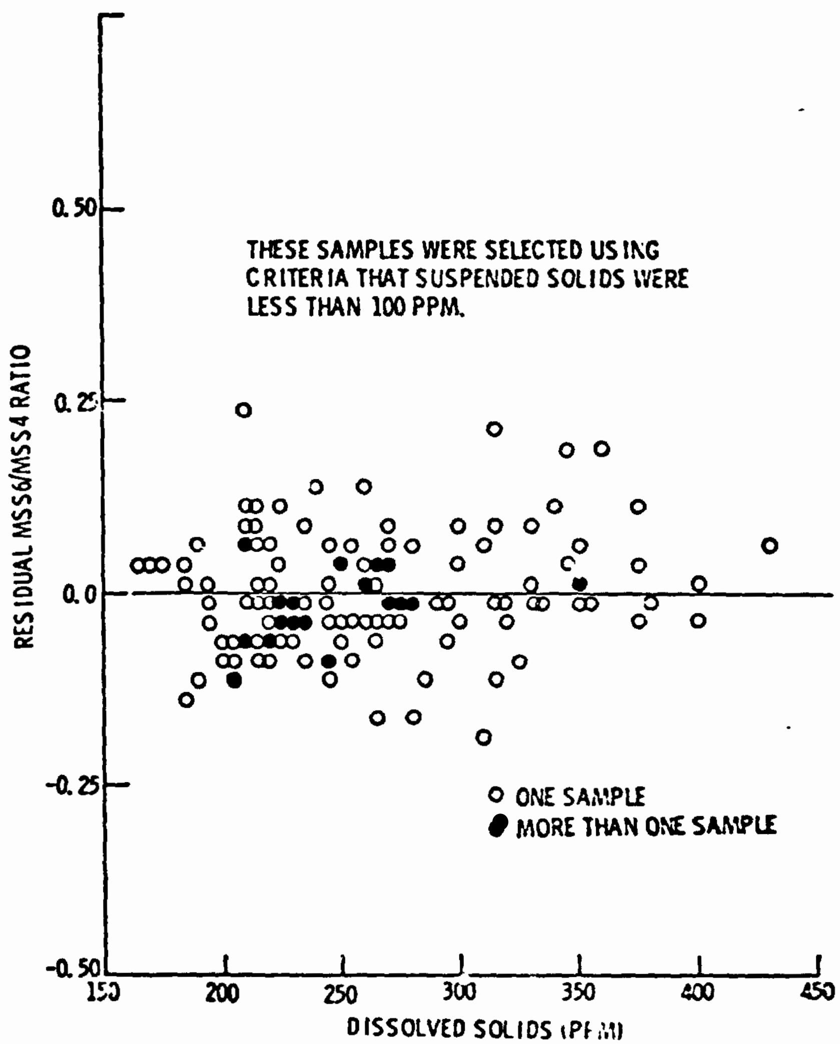


FIGURE 37. RESIDUAL MSS 6/MSS 4 CCT RATIO VS. DISSOLVED SOLIDS FOR 141 SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD. RESIDUAL WAS OBTAINED BY SUBTRACTING LINEAR DEPENDENCE ON SUSPENDED SOLIDS.

of suspended solids against the MSS ratio. The residuals appear to be normally distributed about zero which would be the case if dissolved solids have no significant influence on the MSS ratio. The MSS6/MSS4 residual (figure 37) also does not reveal any correlation with dissolved solids. This residual was obtained by removing the linear ratio dependence on suspended solids. This linear ratio dependence is slightly different than the one shown in figure 14 where suspended solids was the independent variable.

In summary, dissolved solids up to 500 ppm, whose mineralogic characteristics were discussed in the first part of this section, do not influence reflected energy levels present in the four MSS bands.

8.0 CHLOROPHYLL

Based on the analysis presented in section 4.0 and 7.0 it is obvious that MSS correlation with water quality parameters such as chlorophyll and the algal nutrients will be slight, if detectable at all.

The absorption peaks of chlorophyll a, b and c, which are 665 mμ, 645 mμ and 630 mμ respectively, fall inside MSS band 5 (see figure 4). The presence of chlorophyll, therefore, would cause an energy decrease in band 5. The characteristic green color of chlorophyll would cause an increase in band 4 energy which means the MSS5/MSS4 should be negatively correlated with chlorophyll.

Total chlorophyll appears to be largely uncorrelated with suspended sediment (figure 38), so any appreciable effect concentrations up to 20μg/1 have on MSS ratios should be detectable. The MSS5/MSS4 shows no obvious correlation with the composite 13 month sample collection (figure 39). The subset of samples, whose suspended load (> 80 ppm) causes no variation in the MSS5/MSS4 ratio, does not show any significant negative correlation with chlorophyll (figure 40).

The residual MSS5/MSS4 ratio, obtained by removing the linear ratio dependence on suspended solids for samples with < 80 ppm suspended load, is shown in figure 41 (see section 7.0 for further discussion on residuals technique). As can be seen in figure 41, a slight negative correlation with total chlorophyll is beginning to emerge for chlorophyll concentrations $\gtrsim$ 8 μg/l.

Total chlorophyll is also uncorrelated with secchi depth (figure 42). Figure 43 shows the residual MSS5/MSS4 ratio, obtained by subtracting the linear dependence on secchi depth over the range 0 to 0.6 meters, plotted against chlorophyll. This plot also suggests a weak negative correlation between the MSS5/MSS4 ratio and total chlorophyll for concentrations beyond ~ 8 μg/l.

Figures 41 and 43 do not represent independent tests for chlorophyll correlation because secchi depth and suspended solids are correlated (see figure 24). They do, however, establish that the data is internally consistent.

Chlorophyll a, b and c were studied individually using plots similar to figures 38-43. The results were consistent with those for total chlorophyll. In each case, the 3 to 6 samples with highest concentration appeared to be negatively correlated with MSS5/MSS4.

In summary, typical chlorophyll levels in Kansas reservoirs of 0 to 8 μg/l are not detectable by ERTS. There does seem to be a slight negative correlation with MSS5/MSS4 beyond 8 μg/l but there are not enough samples to determine a useful quantitative correlation.

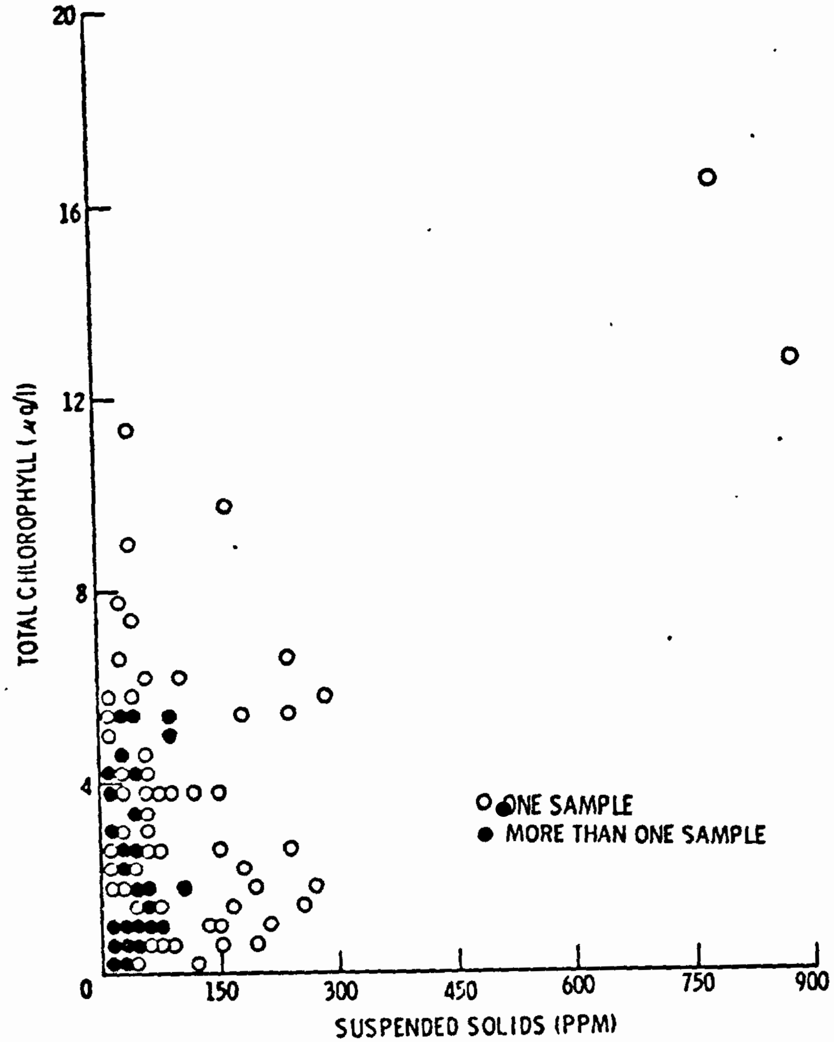


FIGURE 38. TOTAL CHLOROPHYLL VS. SUSPENDED SOLIDS FOR 140 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

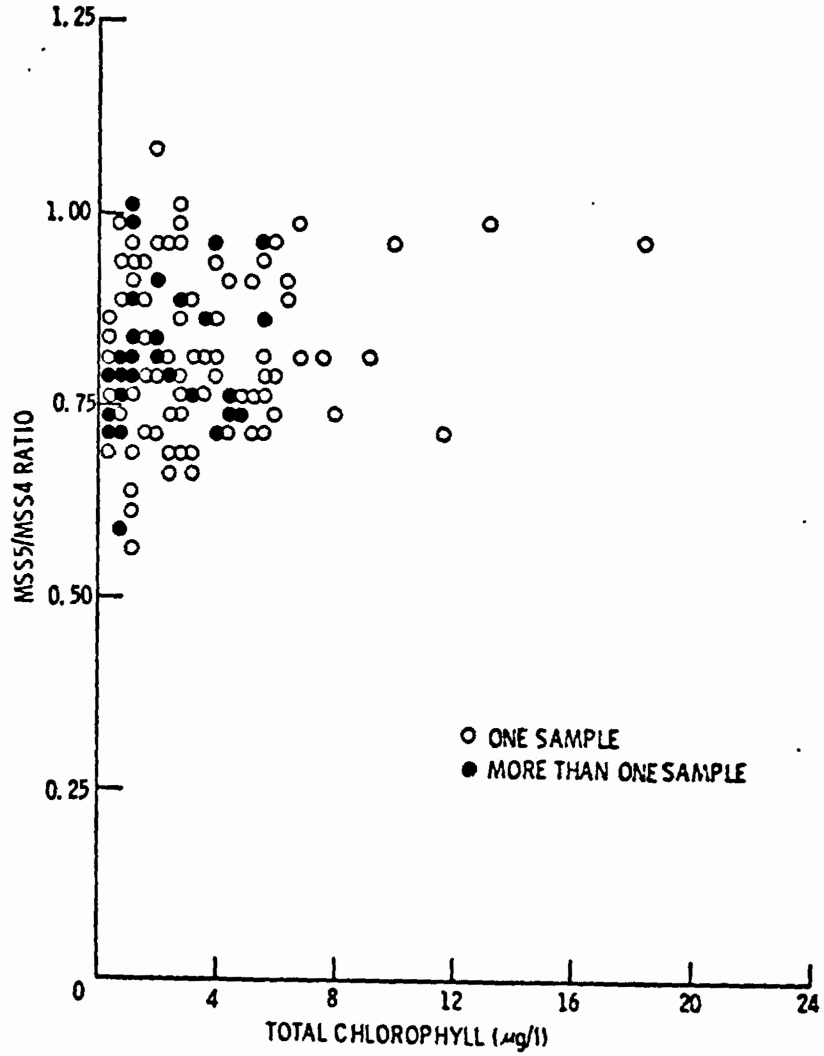


FIGURE 39. MSS 5/ MSS 4 CCT RATIO VS. TOTAL CHLOROPHYLL FOR 140 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

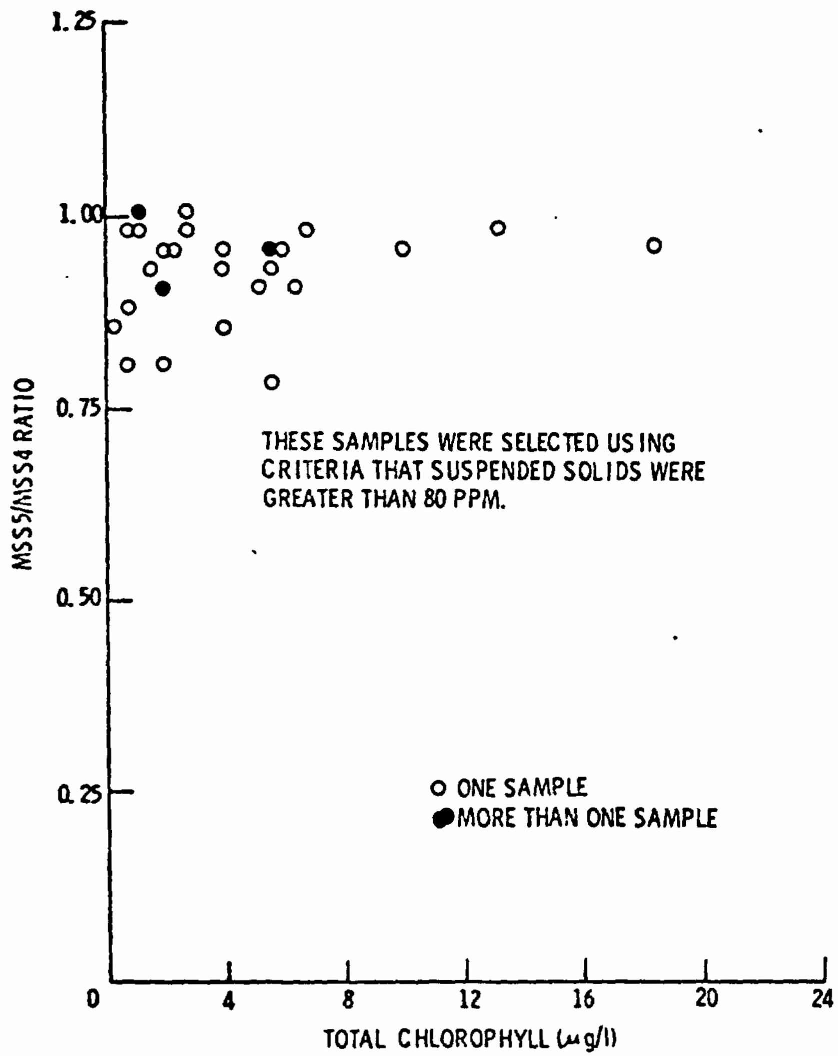
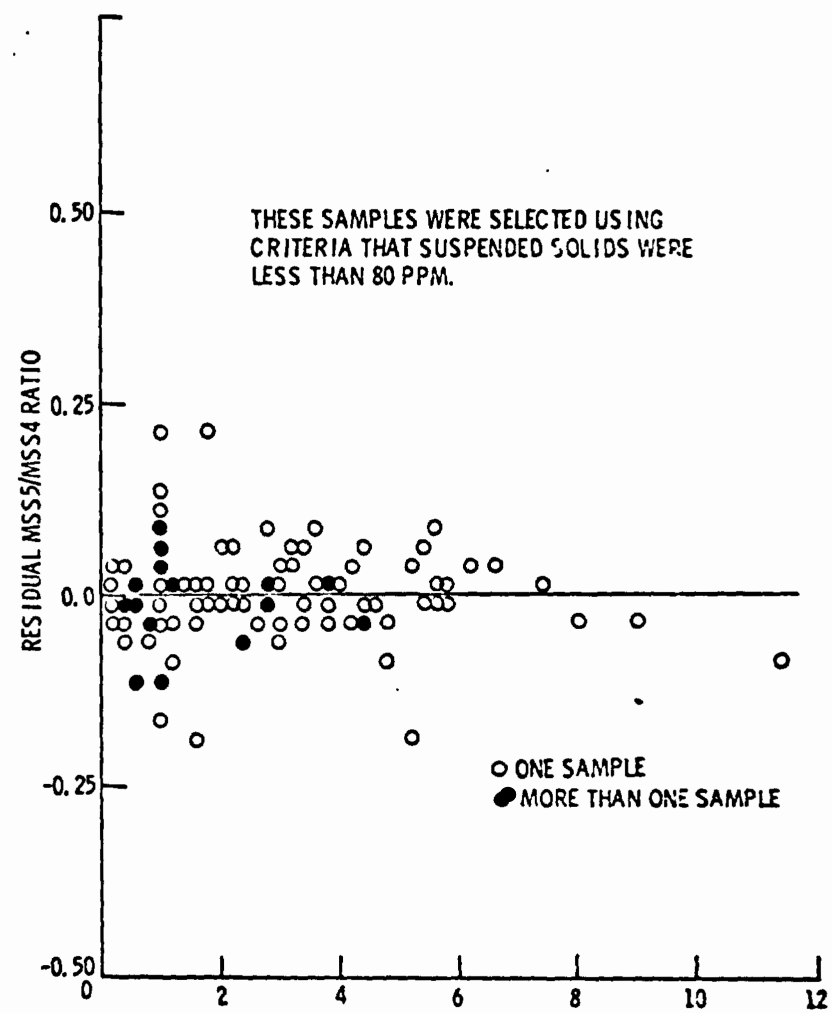


FIGURE 40. MSS 5/ MSS 4 CCT RATIO VS. TOTAL CHLOROPHYLL FOR 30 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.



TOTAL CHLOROPHYLL (µg/l)

FIGURE 41. RESIDUAL MSS 5/MSS 4 CCT RATIO VS. TOTAL CHLOROPHYLL FOR 106 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD. RESIDUAL WAS OBTAINED BY SUBTRACTING LINEAR DEPENDENCE ON SUSPENDED SOLIDS.

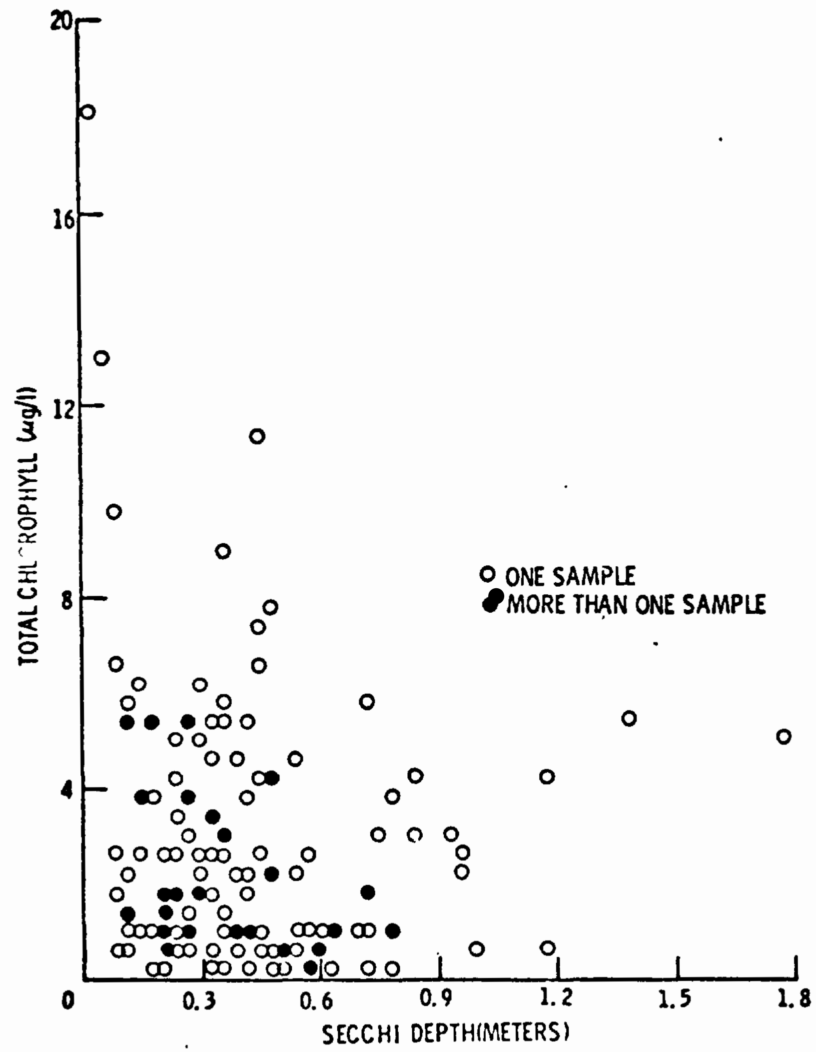


FIGURE 42. TOTAL CHLOROPHYLL VS. SECCHI DEPTH FOR 143 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

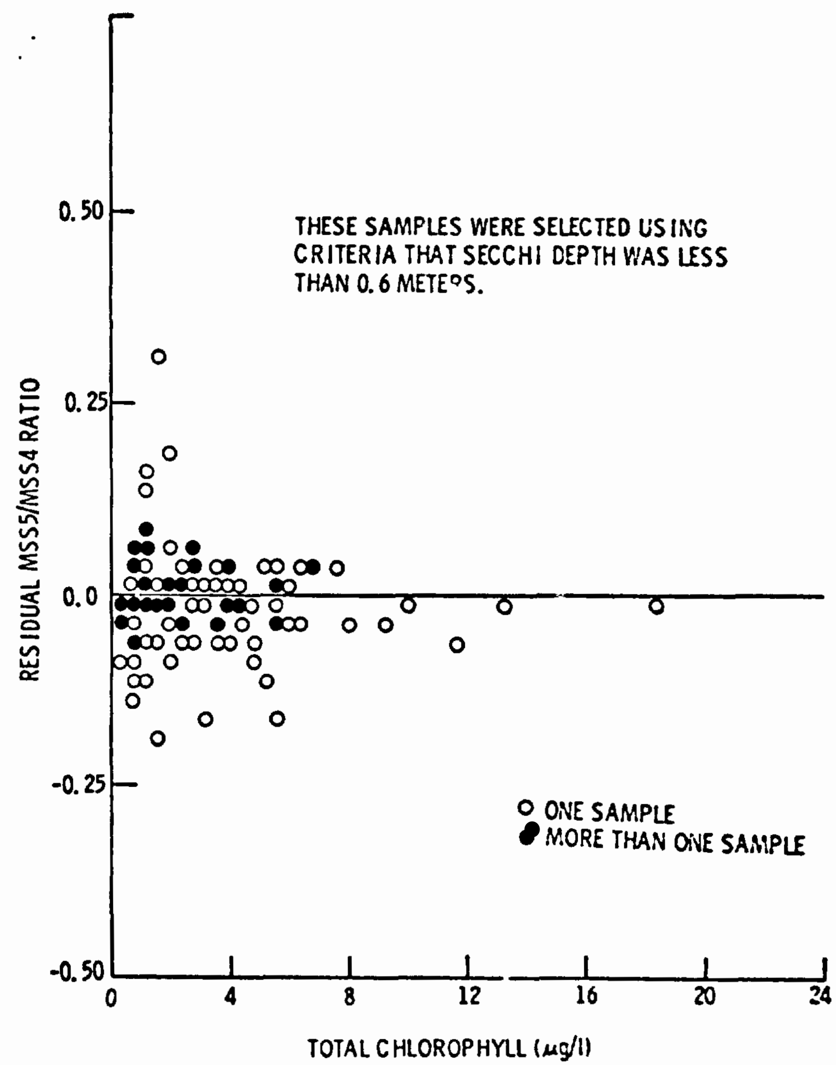


FIGURE 43. RESIDUAL MSS 5/MSS 4 CCT RATIO VS. TOTAL CHLOROPHYLL FOR 114 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD. RESIDUAL WAS OBTAINED BY SUBTRACTING LINEAR DEPENDENCE ON SECCHI DEPTH.

Other workers (Szekielda and Curran, 1973) have found that ERTS is able to detect chlorophyll at ~10 μg/l concentration in relatively clear seawater. In our case, the noise from the relatively high turbidity is probably masking the chlorophyll signal from Kansas reservoirs.

9.0 ALGAL NUTRIENTS

Concentrations of potassium, phosphate and nitrate are plotted against suspended solids (figures 44, 45 and 46). These three algal nutrients were studied for possible influence on reflected energy levels present in the four MSS bands using techniques described in sections 7.0 and 8.0. The results were negative except for some MSS ratio correlation with phosphate. This is due, however, to the fact that phosphate is somewhat correlated with suspended solids (figure 45). About half of the samples had phosphate concentrations below our laboratory detection limit of 0.25 ppm and do not appear in figure 45.

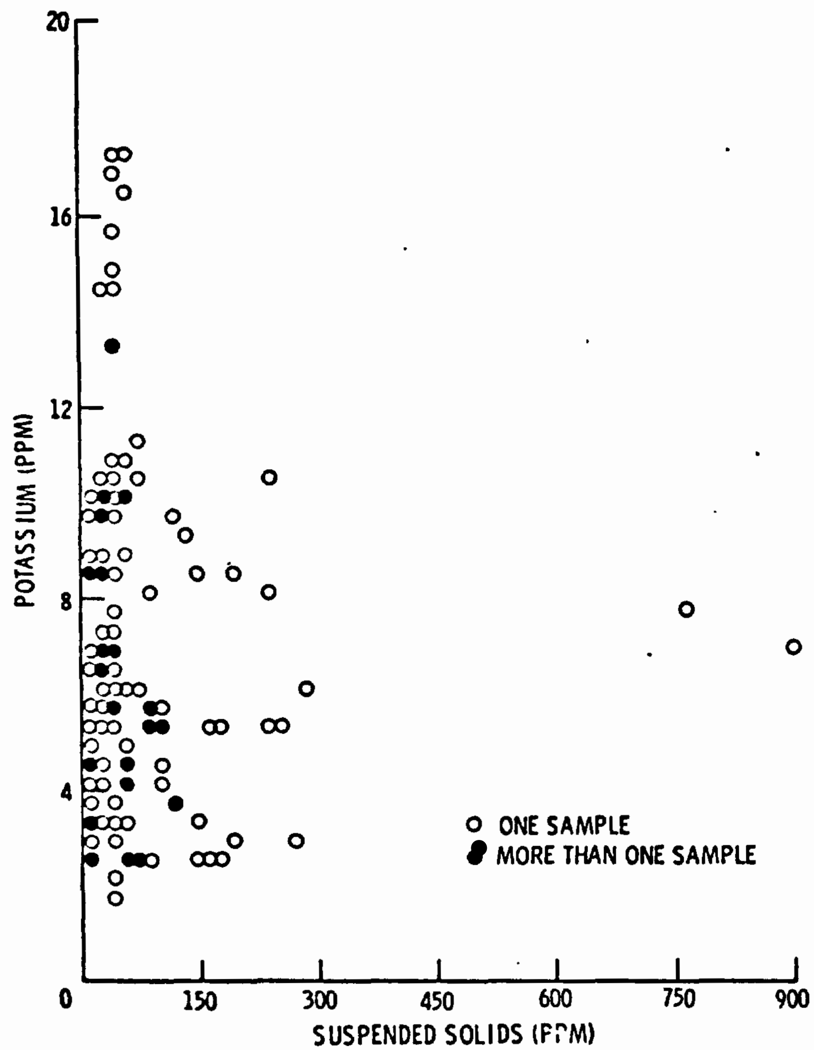


FIGURE 44. POTASSIUM [K] VS. SUSPENDED SOLIDS FOR 140 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

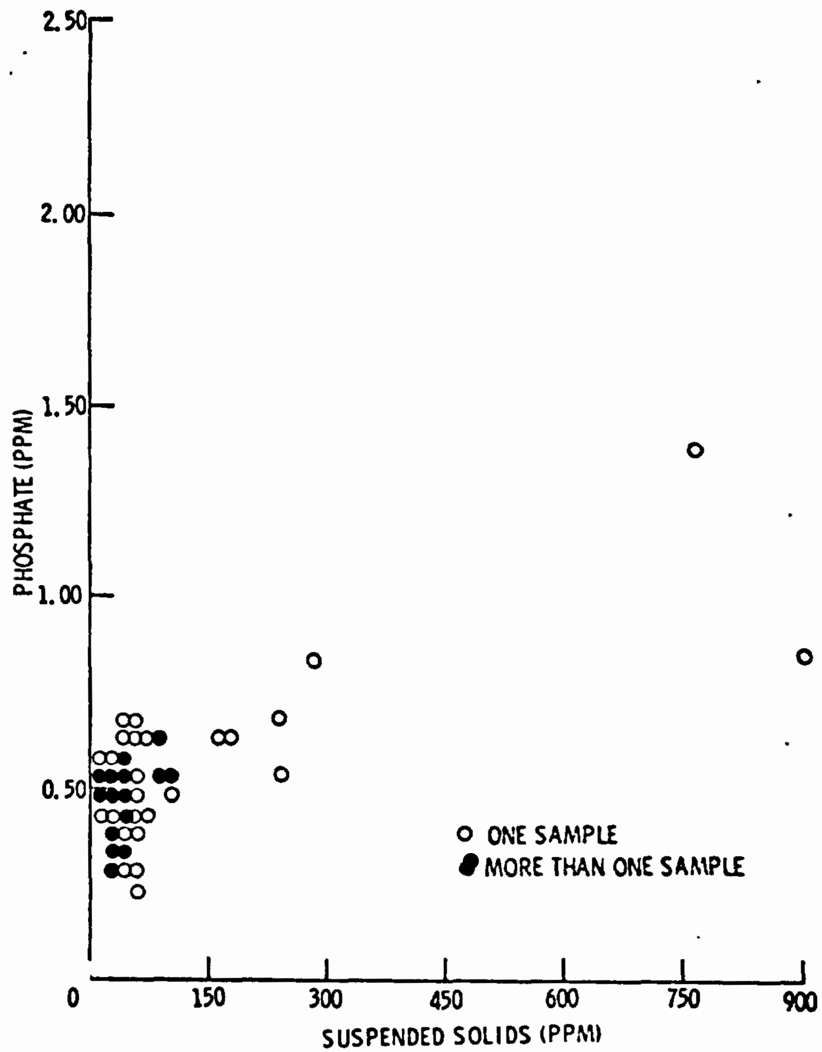


FIGURE 45. PHOSPHATE [PO_4] VS. SUSPENDED SOLIDS FOR 70 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

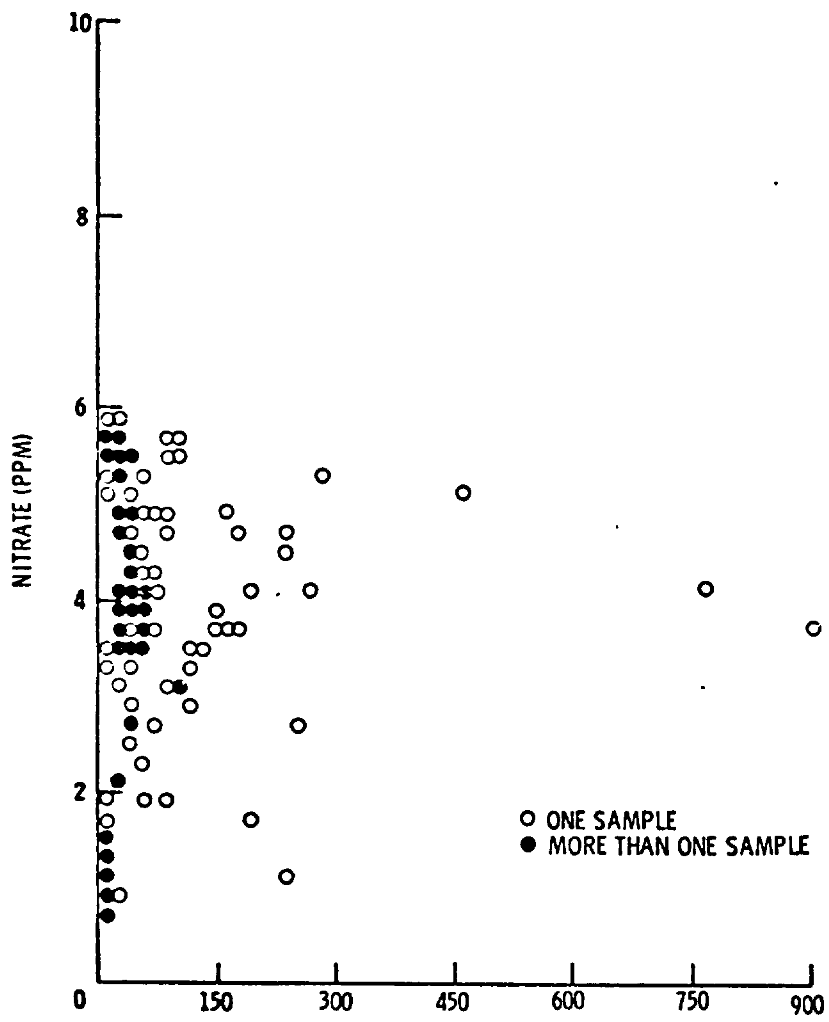


FIGURE 46. NITRATE $[NO_3]$ VS. SUSPENDED SOLIDS FOR 140 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

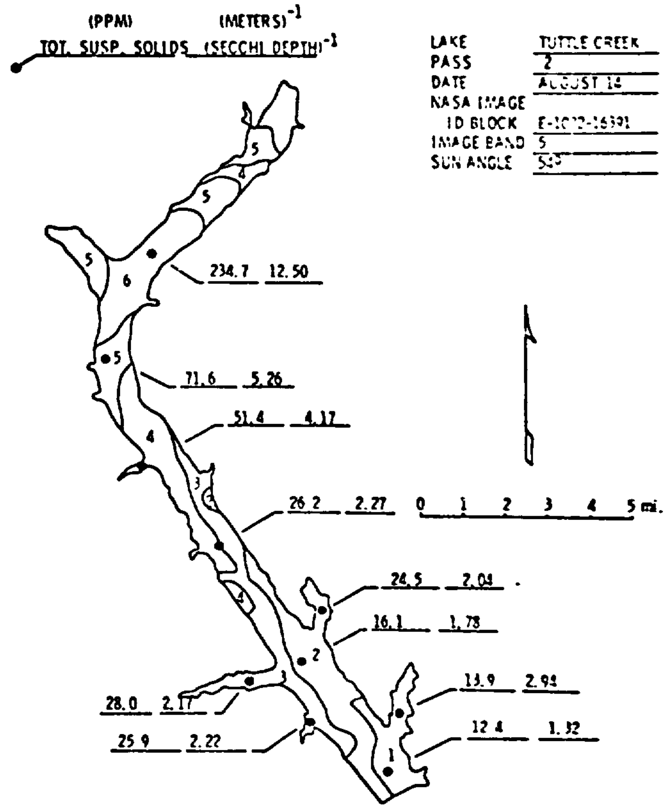


Figure 47. Tuttle Creek Reservoir Gray Levels, 14 August 1972, MSS 5 (IDECS Analysis of NASA Image: ERTS E-1022-16391-5 01)

10.0 CCT VS. POSITIVE TRANSPARENCIES

Approximately 30 cloud-free and ice-free ERTS images of Tuttle Creek and Perry were electronically sliced and displayed on our IDECS system following the method outlined in the fifth paragraph of section 2.0. Gray level contour maps of each image were prepared for comparison with suspended load and secchi measurements. Figure 47 is the MSS5 gray level map for the second cycle over Tuttle Creek Reservoir. Plotted on this map are the sample stations and the total suspended solids and inverse secchi depths recorded at these stations during imaging. These maps were used to produce graphs similar to those using CCT digital levels discussed in previous sections.

In figure 49 IDECS levels are compared with tape levels for a cycle over Perry Reservoir. IDECS levels were normalized to the CCT levels by matching the lowest and highest IDECS levels to the lowest and highest CCT levels respectively. As seen in figure 49 the two methods of analysis compare favorably. Other cycles produced equally favorable results. In general, IDECS levels, once normalized to CCT levels agree well with CCT levels. However, IDECS levels, which are gray levels obtained from 9" transparencies are not useful in an absolute sense. IDECS levels are useful for qualitatively displaying relative suspended load distribution in a reservoir. IDECS levels are not related to a standard scale, as are the CCT levels, so are not as useful qualitatively.

Densitometer measurements were made of reservoir images and the accompanying gray-step scale at the bottom of each image. The gray steps are linearly related to CCT levels so that density measurement can be directly converted to an equivalent CCT level. An example is shown in figure 48. CCT and density values compare quite favorably thus indicating that density measurements would produce quantitative results comparable to those obtained using CCT's.

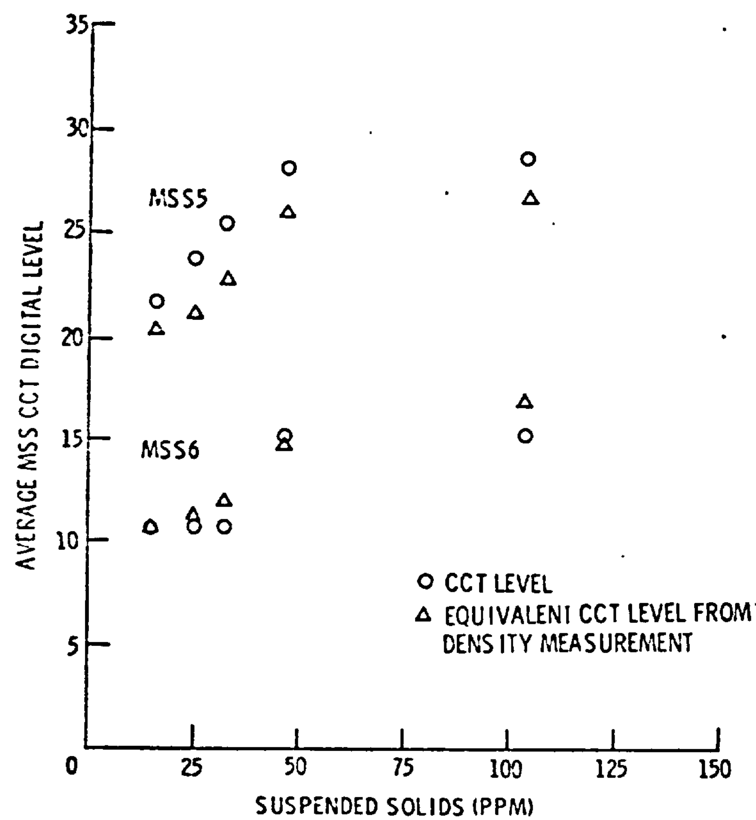


FIGURE 48. COMPARISON OF CCT DIGITAL LEVELS WITH IMAGE DENSITY MEASUREMENTS FOR TUTTLE CREEK RESERVOIR, ERTS CYCLE 4. DENSITY MEASUREMENTS WERE CONVERTED TO EQUIVALENT CCT LEVELS BY USING STEP WEDGE AT BOTTOM OF IMAGE.

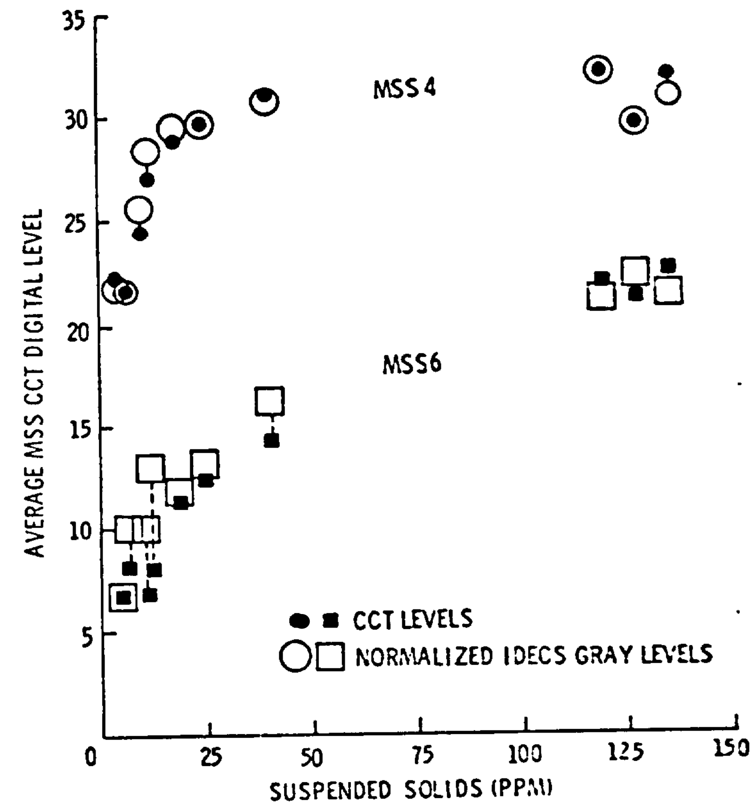


FIGURE 49. COMPARISON OF CCT LEVELS WITH IDECS LEVELS FOR PERRY, ERTS CYCLE 2.

11.0 REGIONALIZATION OF STATE RESERVOIRS

The 19 major federal reservoirs in Kansas were studied during the year of ERTS-1 imagery in an effort to determine regional variations in overall water quality. These lakes are quite variable in size and are located throughout the state in various physiographic, geologic and land-use regions. The seven westernmost lakes are operated by the Bureau of Reclamation the remaining lakes being Corps of Engineers impoundments. For the most part, these are multipurpose reservoirs offering flood protection, water supply and recreation.

Approximately 21 ERTS cycles of imagery over Kansas were received and analyzed. Film analysis was qualitative consisting of value judgements made of the brightness of the reservoirs. Reservoir appearance was given a value from 4 to 0 based on its brightness of ERTS imagery. On this scale 4 = white, 3 = light gray, 2 = medium gray, 1 = dark gray and 0 = black. Values were given with respect to overall scene brightness during that particular cycle, thus these values are to some extent sun angle independent. The larger lakes often display internal tonal variation, such variation is given a range of brightness. The image brightness for the 19 Federal Reservoirs over the 21 ERTS cycles are tabulated in figure 50. The tabulation is incomplete due to snow and ice, cloud cover, and unavailability of imagery, but sufficient data was gathered to draw some conclusions concerning the regionalization of the lakes.

As stated in section 4.0, total suspended solids appear to dominate the reflection from Kansas reservoirs. Thus the values in figure 50 are qualitative estimates of the suspended solids aspect of water quality for the state's major reservoirs. In an attempt to uncover regional variations three parameters were devised which help define the long range behavior of the state's reservoirs. These parameters are the brightness of the MSS6 and 7 images, the darkness of the MSS 4 and 5 images, and the variation within the reservoir. The first two parameters are somewhat mutually exclusive and provide information concerning the amount of suspended solids. Only high amounts of suspended solids give bright IR images. Conversely only low amounts of suspended solids give dark images in the visible range due to greater water penetration and scattering from suspended particles. The tonal variation within the reservoir gives insight into the mixing characteristics of the reservoir.

Within each cycle in figure 50 the maximum value of each of the three parameters was determined and tallies were given to the appropriate reservoirs. The results are shown in figure 51 in which the lakes are grouped according to physiographic province in which they occur according to the physiographic map of Kansas produced by Schoewe (1949). For each reservoir there is a tally for each cycle in which it had the brightest infrared

CYCLE	BAND #	PERRY	POMONA	REDMOND	TORONTO	FALL RIVER	ELK CITY	TUTTLE CREEK	MILFORD	COUNCIL GROVE	MARION	CHENEY	KANOPOLIS	LOVEWELL	WACONDA	WILSON	KIRWIN	WEBSTER	CEDAR BLUFF	NORTON
1	4	3-1	2-1	3	3	2	2	NA	NA	NA	●	●	●	2	2	●	2-1	1	3-1	2
	5	3-1	2-1	3	3	2	2	NA	NA	NA	NA	●	●	2	1	●	2-1	1	2-0	3-2
	6	2-0	1-0	1	1	0	0	NA	NA	NA	0	●	●	0	0	●	1-0	1-0	1-0	2-0
	7	1-0	0	0	0	0	0	NA	NA	NA	NA	●	●	0	0	●	0	0	0	0
2	4	3-2	2	NA	NA	NA	NA	3-2	3-1	2	2	3	3	NA	NA	3-2	2	2	3-1	2
	5	3-1	2-1	NA	NA	NA	NA	3-2	3-2	2	2-1	2	3-2	NA	NA	2-1	2-1	2	3-1	3-2
	6	2-0	0	NA	NA	NA	NA	2-0	2-0	0	0	1-0	1-0	NA	NA	0	1-0	1	1-0	1-0
	7	NA	NA	NA	NA	NA	NA	1-0	0	0	0	0	0	NA	NA	NA	0	0	0	0
3	4	3-2	2	3	NA	NA	NA	NA	NA	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5	3-2	2	3	NA	NA	NA	NA	NA	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6	1-0	0	1-0	NA	NA	NA	NA	NA	1-0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	4	2-1	1	2	NA	NA	NA	3	2	2	1	2	2	NA	NA	1	NA	1	3-1	NA
	5	3-1	2-1	3-2	NA	NA	NA	3	3-1	3-2	2-1	2-1	2	NA	NA	1	NA	1	4-0	NA
	6	1-0	0	1-0	NA	NA	NA	1-0	1-0	1-0	0	0	1-0	NA	NA	0	NA	0	1-0	NA
	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	4	●	●	●	NA	NA	NA	3	2	2	0	1	2	●	●	●	●	●	●	●
	5	●	●	●	NA	NA	NA	2	2-1	2	1	1-0	2	●	●	●	●	●	●	●
	6	●	●	●	NA	NA	NA	0	0	0	0	0	0	●	●	●	●	●	●	●
	7	●	●	●	NA	NA	NA	0	0	0	0	0	0	●	●	●	●	●	●	●
6	4	NA	NA	NA	NA	NA	NA	3	2	2	NA	2	3	2-1	2-1	2	2-1	2-1	●	1
	5	NA	NA	NA	NA	NA	NA	2	1	1	1	2	3	1-0	1-0	1	1	1	●	2
	6	NA	NA	NA	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	1-0	●	1
	7	NA	NA	NA	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	●	0
7	4	●	●	●	●	●	●	NA	NA	2	NA	●	●	●	●	●	●	●	●	NA
	5	●	●	●	●	●	●	NA	NA	2	NA	●	●	●	●	●	●	●	●	NA
	6	●	●	●	●	●	●	NA	NA	1	NA	●	●	●	●	●	●	●	●	NA
	7	●	●	●	●	●	●	NA	NA	1	NA	●	●	●	●	●	●	●	●	NA
8	4	NA	2	3	3	3	2	3	2	2	1	2-3	3	2	1	1	2	2	2-1	2
	5	NA	2	1	2	2	1	3	1	1	0	2-1	1	0	0	0	1	1-0	0	1
	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	4	○	○	○	○	○	○	●	●	○	●	●	○	●	●	●	○	○	○	3
	5	○	○	○	○	○	○	●	●	○	●	●	○	●	●	●	○	○	○	3
	6	○	○	○	○	○	○	●	●	○	●	●	○	●	●	●	○	○	○	3
	7	○	○	○	○	○	○	●	●	○	●	●	○	●	●	●	○	○	○	0
10	4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
11	4	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●
	5	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●
	6	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●
	7	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●
12	4	○	○	○	3	1	3	2-0	2-0	3	2	0	2-0	○	○	●	○	●	●	●
	5	○	○	○	3	1	3	2-0	4-0	3	2-1	0	1-0	○	○	●	○	●	●	●
	6	○	○	○	1	0	1	2-0	3-0	0	0	0	0	○	○	●	○	●	●	●
	7	○	○	○	0	0	0	0	0	0	0	0	0	○	○	●	○	●	●	●
13	4	●	●	●	●	●	●	2	2	2	2	●	1	●	●	●	●	●	●	●
	5	●	●	●	●	●	●	2	2	2	2	●	1	●	●	●	●	●	●	●
	6	●	●	●	●	●	●	2-0	2-0	2-0	2-0	●	1	●	●	●	●	●	●	●
	7	●	●	●	●	●	●	0	0	0	0	●	0	●	●	●	●	●	●	●
14	4	NA	NA	NA	3	3	3	●	●	●	3	●	3	●	●	●	1	2	3-1	1
	5	NA	NA	NA	2	2	3	●	●	●	2	●	2	●	●	●	1	1-0	1	1
	6	NA	NA	NA	2	2-1	2-0	●	●	●	2	●	0	●	●	●	0	0	0	0
	7	1-0	1-0	1-0	0	0	0	●	●	●	1	●	0	●	●	●	0	0	0	0
15	4	NA	NA	3	3	3	●	3	3-1	3	2	3	3	2	2	3	1	1	●	●
	5	NA	NA	2	2	2	●	3-2	3-1	3	2	2	3	NA	2	1	1	1	●	●
	6	NA	NA	1	1	1	●	3-0	2-0	2	2-1	0	2-0	0	0	0	0	0	●	●
	7	NA	NA	1	0	0	●	2-0	1-0	0	0	0	0	0	0	0	0	0	●	●
16	4	3	2	3	NA	1	3	3-2	2	3	2	2	2-1	2	●	●	●	●	●	●
	5	3-2	3-2	2-1	NA	1	3	3-2	3-2	3	2	2	2-1	2	●	●	●	●	●	●
	6	1-0	1	1-0	0	0	0	1	0	1	1-0	0	1-0	0	●	●	●	●	●	●
	7	0	0	1	0	0	0	0	0	0	0	0	0	0	●	●	●	●	●	●
17	4	NA	NA	2	3-2	2	2	3-2	3-2	3	3	3	3	2	1	1	1	1	2-1	1
	5	3-2	2	1	NA	NA	NA	3-2	3-2	3	3	3	2	2	1	1	1	1	1	1
	6	1-0	2-0	0	0	1	0	1-0	2-0	1	1	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	4	●	●	○	○	○	○	○	●	2	2	2	2	2	●	●	1	1	2-1	2
	5	●	●	○	○	○	○	○	●	2	2	2	2	1	●	●	1	1	2-0	1
	6	●	●	○	○	○	○	○	●	1	0	0	0	0	●	●	0	0	0	0
	7	●	●	○	○	○	○	○	●	0	0	NA	0	0	●	●	0	0	0	0
19	4	3	3	3	3	3	3	1	3-2	2	2	2	2	3	2	3-2	1	1	3-1	2
	5	3	3	3	3	3	3	1	2	3	2	2	2	3-2	1	3-1	1	1	2-1	2
	6	0	1	1	1	1	1	0	1-0	0	0	0	0	0	0	0	0	0	NA	0
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0
20		●	NA	NA	3	2	3	3-2	2-1	3	2	2	2	2	2	3-2	3-2	2	3-1	2
	5	●	NA	NA	3	2	3	2-1	2-1	3	2-1	1	1	0	1	2-1	1	1	2-1	1
	6	●	1	1	1	0	1-0	0	1-0	1	0	0	0	0	0	0	0	0	0	0
	7	●	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	4	●	●	●	●	2	●	●	●	●	●	●	●	●	NA	1	2	2	●	●
	5	●	●	●	●	2	●	●	●	●	●	●	●	●	NA	1	2	2	●	●
	6	●	●	●	●	0	●	●	●	●	●	●	●	●	0	0	0	0	●	●
	7	●	●	●	●	0	●	●	●	●	●	●	●	●	0	0	0	0	●	●

NA - Not Available ○ - Snow and Ice Cover ● - Cloud Cover

0 - Black 1 - Dark Gray 2 - Medium Gray 3 - Light Gray 4 - White

FIGURE 50. GREY LEVEL EXPRESSION OF THE 19 MAJOR KANSAS RESERVOIRS DURING 21 ERTS-1 CYCLES.

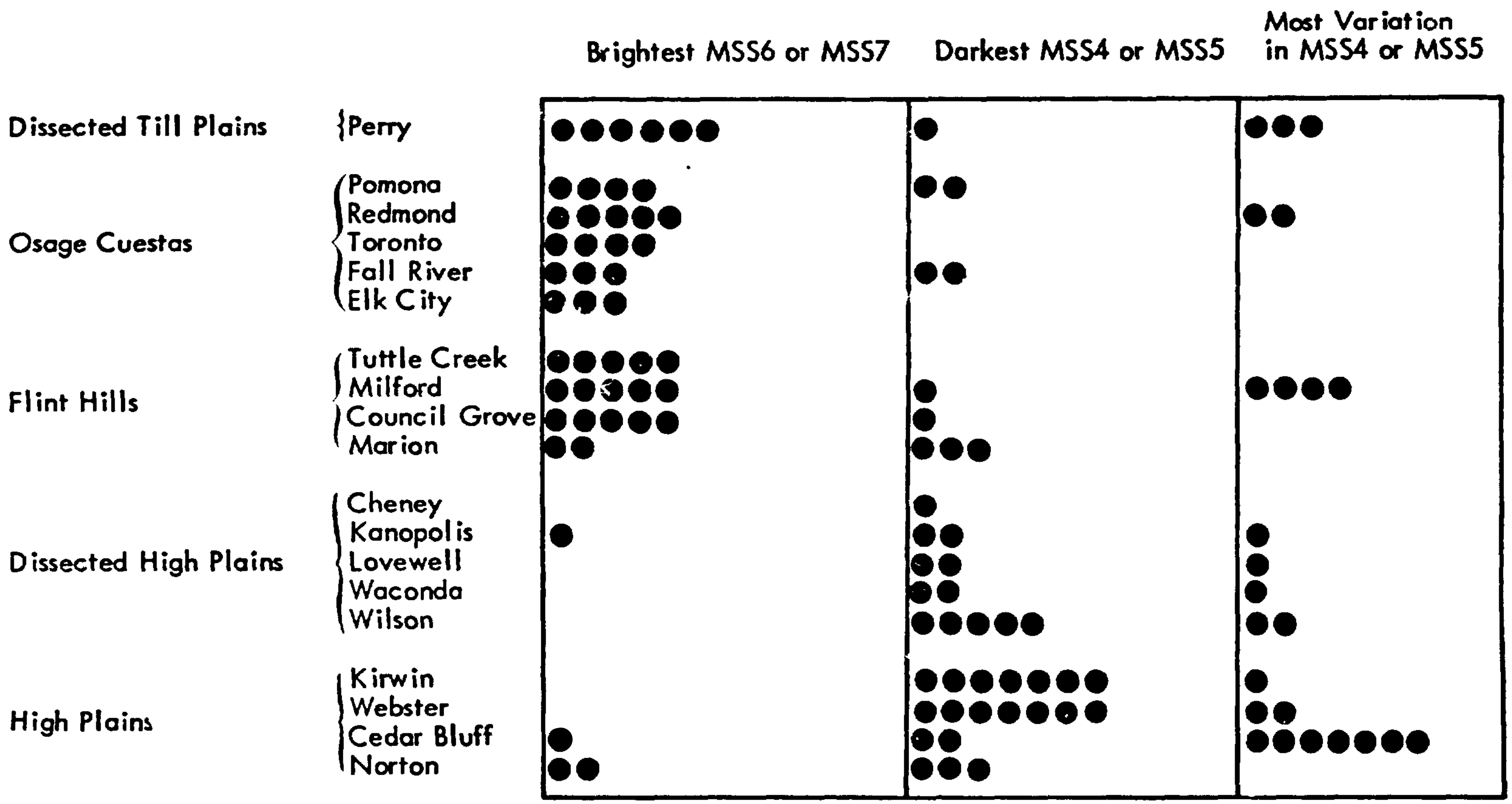


FIGURE 51. SUMMARY OF KANSAS RESERVOIR BEHAVIOR ON ERTS-1 IMAGERY DURING 21 CYCLES.

image or the darkest visible range images or the greatest MSS 5 or 4 tonal variation within the reservoir.

As can be seen in figure 51 the lakes having the brightest infrared images indicative of very turbid water are usually located in the Dissected Till Plains, Osage Cuestas or the Flint Hills which make up the eastern third of the state. Those lakes located in the High Plains and the Dissected High Plains in the western two thirds of the state seldom have the brightest infrared images. Conversely these western lakes more often have the darkest images in the visible bands indicative of very clear water, whereas the eastern lakes usually have brighter images in the visible range. Three lakes show the most amount of internal tonal variation in the visible bands; Perry, Milford and Cedar Bluff.

The fact that the western lakes consistently appear to have smaller amounts of suspended solids than their eastern counterparts appears due to two factors.

1. The amount of annual precipitation received in the state decreases from about 40 inches in the southeast to less than 20 inches in the west. This results in a decrease of average annual runoff from nearly 10" in the southeast to less than 0.2" in the west (USGS 1970). These low runoff amounts in the west cause lower inflow into the western lakes. In fact some of the streams feeding the reservoirs become intermittant during dry periods. The paucity of rainfall causes longer periods between rains and allows the settling out of much of the suspended load.

2. The second contributing cause of clearer lakes in the west may be related to differing land uses between eastern Kansas and western Kansas. In the east the major streams possess well defined floodplains in which crop land is extensive. Toward the west the floodplains become narrower and less conducive to intensive agriculture and are generally used as rangeland thus retaining their natural cover of vegetation. As a result the protection of soil in proximity to streams is greater in the west than in the east and the lakes tend to be clearer with less suspended solids.

The three lakes displaying the greatest internal variation in the visible bands are Perry, Milford, and Cedar Bluff. Both Perry and Milford have causeways bearing highways across their upper ends. These causeways are filled in except for a small span located over the old river channel. These causeways tend to trap sediment in the upper parts of the lakes causing a sharp contrast in tone on either side of the causeway. And an even greater contrast exists between the turbid water above the causeway and the clear water near the dam.

Cedar Bluff consistently displays sharp internal variations also with the upper end being very bright and the lower end dark. A delta-type deposit appears to have formed in its upper end in very shallow water. Wind generated waves may stir up this silt and sand causing the upper end to appear very bright on imagery. Because of the coarseness of the suspended material it apparently settles out quite readily in deeper quieter water explaining why the lower two-thirds of the lake is consistently clear.

12.0 CONCLUSIONS

ERTS MSS ratios derived from CCT's are very effective for quantitative detection of suspended solids up to at least 900 ppm, which is the limit of this investigation. The actual upper limit on suspended solids ERTS can detect is probably substantially higher. Typical midcontinent variables such as sun angle, wind speed and temperature do not significantly affect MSS ratios.

Dissolved solids up to at least 500 ppm are not correlated with ERTS imagery. The algal nutrientspotassium, phosphate and nitrate at concentration levels up to 20, 2 and 10 ppm respectively are not correlated with ERTS imagery. The MSS5/MSS4 ratio appears to be weakly correlated with total chlorophyll above concentration levels of ~ 8 μg/l, but more data are needed to confirm this.

Density measurements from the NASA 9" positive transparencies compare favorably with CCT levels. It would be relatively simple and inexpensive for interested agencies or groups to obtain suspended load information by using a macrodensitometer.

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